RECENT OCCURRENCES AND REGULATION ENFORCEMENT OF PER- AND POLYFLUORINATED SUBSTANCES IN DRINKING WATER

Nurlin Abu Samah
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang Al-Sultan Abdullah
E-mail: nurlin@umpsa.edu.my

Per- and polyfluorinated substances (PFAS) have emerged as significant contaminants in drinking water sources, garnering widespread attention due to their persistence, toxicity, and potential health risks. This article provides a comprehensive overview of recent occurrences of PFAS in drinking water and the regulatory measures enforced to mitigate their impact. It synthesizes current research findings, highlighting the prevalence of PFAS contamination across various regions and its implications for public health. Additionally, it examines the regulatory landscape governing PFAS, including legislative initiatives and enforcement actions aimed at monitoring and controlling these contaminants. By analysing the intersection of scientific research and regulatory efforts, this abstract offers insights into the ongoing challenges and advancements in addressing PFAS contamination in drinking water.

1.0 Introduction

Harmful PFAS are an urgent public health and environmental issue facing communities across the United States. PFAS have been manufactured and used in various industries in the United States and around the world since the 1940s, and they are still being used today (Kim et al., 2023). Due to their extensive use, PFAS can be found in surface water, groundwater, soil, and air—from remote rural areas to densely populated urban centres. A growing body of scientific evidence shows that exposure to certain PFAS at specific levels can adversely impact human health and other living organisms. Despite these concerns, PFAS are still used in a wide range of consumer products and industrial applications. Researchers at the Environmental Protection Agency and their partners across the country are working hard to answer critical questions about PFAS: how to better and more efficiently detect and measure PFAS in our air, water, soil, and fish and wildlife; how much people are exposed to PFAS; how harmful PFAS are to people and the environment; how to remove PFAS from drinking water; and how to manage and dispose of PFAS.

2.0 Per- and Polyfluorinated Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a group of chemicals used to make fluoropolymer coatings and products that are resistant to heat, oil, stains, grease, and water. These coatings can be found in a variety of products. PFAS, including perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorohexanesulfonic acid (PFHxS), hexafluoropropylene oxide-dimer acid (HFPO-DA), and perfluorobutanesulfonic acid (PFBS), are of concern because they do not break down in the environment. They can move through soils, contaminate drinking water sources, and bioaccumulate in fish and wildlife (Bodus et al., 2024). PFAS are found in rivers and lakes, and many animal species on land and in water. Detailed information regarding each type of PFAS will be discussed further.

2.1 *Perfluorooctanoic acid (PFOA)*

PFOA (Figure 1) is a man-made chemical primarily used in the production of fluoropolymers, which are substances with special properties such as resistance to heat, oil, stains, grease, and water. These properties make PFOA and related chemicals useful in a wide range of industrial and consumer applications, including non-stick cookware, waterproof clothing, stain-resistant fabrics, food packaging, and firefighting foams (Rehman et al., 2023). However, PFOA is also a persistent organic pollutant, meaning it resists degradation in the environment and can accumulate in living organisms over time. It has been linked to various health concerns, including cancer, thyroid disease, developmental effects, and reproductive harm. Recently, PFOA was found in the Hong Kong water supply at much higher concentrations compared to other PFAS (tap water: 39.7 ng/L; bottled water: 32.6 ng/L), followed by PFOS (tap water: 8.6 ng/L; bottled water: 7.1 ng/L). Interestingly, bottled water in Thailand contained higher levels of PFAS (especially PFOA and PFOS) compared to tap water (Wee & Aris, 2023). As a result, many countries and regulatory agencies have taken steps to restrict or phase out the use of PFOA and related chemicals.

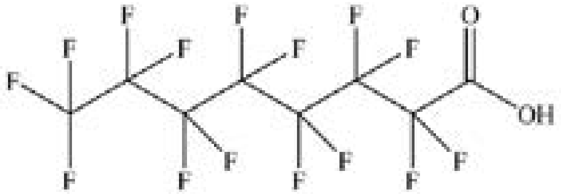

Figure 1 Chemical structure of PFOA

2.2 *Perfluorooctane sulfonic acid (PFOS)*

Like PFOA, PFOS is a man-made chemical that belongs to the PFAS group. PFOS has historically been used in a variety of industrial and consumer products due to its unique properties, including its ability to repel water, oil, and stains. It has been used in firefighting foams, stain-resistant fabrics, carpets, upholstery, food packaging, and more. Like PFOA, PFOS is also a persistent organic pollutant, meaning it remains in the environment for a long time without breaking down. It can accumulate in organisms and has been found in the blood of humans and wildlife worldwide. Based on the reviews of studies conducted in Asia, China reported the highest concentration of PFOS in its groundwater samples, exceeding the US EPA recommended limit for drinking water health advisory (Tang et al., 2023). PFOS has been associated with various health effects, including developmental delays, liver toxicity, immune system impacts, and potentially cancer. Due to these concerns, many countries have restricted or phased out the production and use of PFOS and related chemicals, and efforts are ongoing to address their presence in the environment and human exposure.

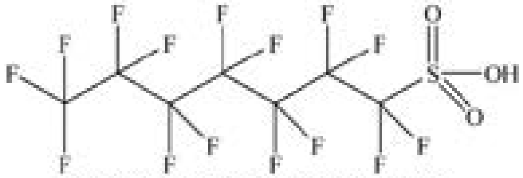

Figure 2 Chemical structure of PFOS.

2.3 *Perfluorononanoic acid (PFNA)*

PFNA is a type of perfluoroalkyl acid (PFAA) that belongs to the broader group of PFAS. PFNA (Figure 3) is a synthetic chemical compound consisting of a fluorinated chain with nine carbon atoms and a carboxylic acid functional group (-COOH) at one end. Like other PFAS, PFNA has been used in various industrial and commercial applications due to its unique properties, including oil and water repellence, heat resistance, and chemical stability. It has been used in products such as stain-resistant coatings, firefighting foams, lubricants, and in the production of certain polymers. However, PFNA, like many other PFAS compounds, is resistant to degradation in the environment and can persist for long periods. It has been detected in water, soil, air, and biological tissues globally. Exposure to PFNA has been associated with potentially adverse health effects, including developmental toxicity, liver toxicity, immune system effects, and potential carcinogenicity. As a result, regulatory agencies and governments have taken action to monitor and regulate PFNA and other PFAS compounds to minimize environmental contamination and human exposure.

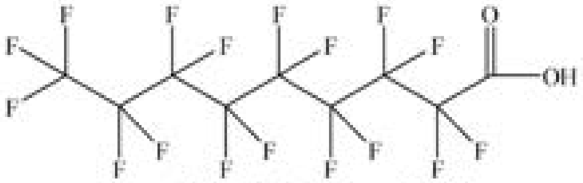

Figure 3 Chemical structure of PFNA.

2.4 *Perfluorohexanesulphonic acid (PFHxS)*

PFHxS (Figure 4) is a member of the PFAS family. It is a synthetic chemical compound consisting of a fluorinated carbon chain with six carbon atoms and a sulfonic acid functional group (-SO3H) at one end. Like other PFAS compounds, PFHxS is used in various industrial and consumer applications due to its unique properties, including its ability to repel water, oil, and stains. It has been used in products such as firefighting foams, surface treatments, and in the manufacture of certain polymers and textiles. PFHxS, like many other PFAS compounds, is persistent in the environment and can accumulate in organisms over time. It has been detected in water, soil, air, and biological tissues globally. Exposure to PFHxS has been associated with potentially adverse health effects, including developmental toxicity, liver toxicity, immune system effects, and potential reproductive health effects. Due to concerns about the persistence of PFHxS in the environment and its potential health effects, regulatory agencies and governments have taken action to monitor and regulate PFHxS and other PFAS compounds to minimize environmental contamination and human exposure.

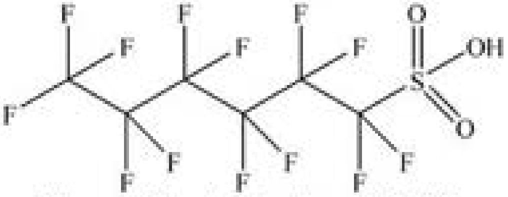

Figure 4 Chemical structure of PFHxS.

2.5 *Hexafluoropropylene oxide-dimer acid (HFPO-DA) (GenX Chemicals)*

HFPO-DA (Figure 5) is a chemical compound that belongs to the group of PFAS. It is also known by the trade name GenX. HFPO-DA is a synthetic compound used in industrial processes, particularly in the production of fluoropolymers.

HFPO-DA is a replacement for PFOA, a PFAS compound that has been phased out or regulated due to concerns about its persistence in the environment and potential health effects. HFPO-DA was introduced as a replacement because it was thought to be less persistent and potentially less harmful. However, studies have shown that HFPO-DA and its derivatives, including perfluorohexanoic acid (PFHxA), can also persist in the environment and have been detected in water sources, soil, and even human blood serum. Concerns have been raised about the potential health effects of HFPO-DA and its derivatives, although research on these effects is still ongoing. Overall, HFPO-DA is a compound of interest due to its widespread use in industrial processes and its potential environmental and health impacts. Regulatory agencies are monitoring the presence of HFPO-DA and considering measures to minimize exposure and mitigate its effects.

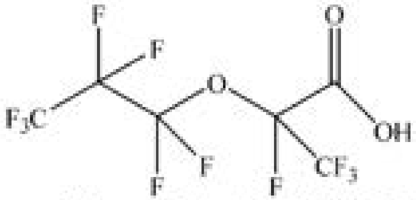

Figure 5 Chemical structure of HFPO-DA.

2.6 *Perfluorobutane sulfonate (PFBS)*

PFBS (Figure 6) is a type of perfluoroalkyl sulfonic acid that falls under the broader category of PFAS. It is a synthetic compound with a fluorinated carbon chain consisting of four carbon atoms and a sulfonic acid functional group (-SO3H) at one end. Like other PFAS compounds, PFBS has been used in various industrial and consumer applications due to its unique properties, including its ability to repel water, oil, and stains. It has been used in products such as surfactants, firefighting foams, and in the production of certain polymers. PFBS, similar to other PFAS compounds, can persist in the environment for long periods without breaking down and has been detected in water, soil, air, and biological tissues globally. Exposure to PFBS has been associated with potentially adverse health effects, including developmental toxicity and impacts on liver and thyroid function, although research into the specific health effects is ongoing. Regulatory agencies and governments have monitored and regulated PFBS and other PFAS compounds to minimize environmental contamination and human exposure.

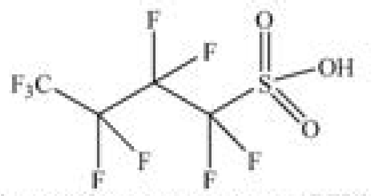

Figure 6 Chemical structure of PFBS.

3.0 Recent Regulation Enforcement Towards PFAS in Drinking Water

Under the Safe Drinking Water Act (SDWA), the Environmental Protection Agency (EPA) has the authority to establish enforceable National Primary Drinking Water Regulations (NPDWRs) for drinking water contaminants and to require monitoring of public water supplies. To date, the EPA has regulated more than 90 drinking water contaminants but has not established national drinking water regulations for PFAS. On April 10, 2024, the EPA announced the final National Primary Drinking Water Regulation (NPDWR) for six PFAS. The EPA has established enforceable Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs) for PFAS in drinking water. Below are the EPA-approved MCLs for various types of PFAS (Table 1).

4.0 The final rule requirement set by the EPA

Public water systems must monitor these PFAS and have three years to complete the initial monitoring (by 2027), followed by ongoing compliance monitoring. Additionally, water utilities must inform the public of the levels of these PFAS in their drinking water starting in 2027. Public water systems have five years (until 2029) to implement solutions to reduce these PFAS if monitoring shows that drinking water levels exceed these MCLs. After five years (2029), public water systems with PFAS levels in their drinking water that violate one or more of these MCLs must take action to reduce PFAS levels and must provide notification to the public of the violation.

References

1. Bodus, B., O'Malley, K., Dieter, G., Gunawardana, C., & McDonald, W. (2024). Review of emerging contaminants in green stormwater infrastructure: Antibiotic resistance genes, microplastics, tire wear particles, PFAS, and temperature. Science of the Total Environment, 906 (September 2023), 167195. https://doi.org/10.1016/j.scitotenv.2023.167195.
2. Kim, M., Kim, S. H., Choi, J. Y., & Park, Y. J. (2023). Investigating fatty liver disease-associated adverse outcome pathways of perfluorooctane sulfonate using a systems toxicology approach. Food and Chemical Toxicology, 176, 113781. https://doi.org/10.1016/J.FCT.2023.113781.
3. Pfas, F., Primary, N., Water, D., & April, R. (2024). EPA's Final PFAS National Primary Drinking Water Regulation: Monitoring and Reporting Fact sheet. In Environmental Protection Agency (Issue April).
4. Rehman, A. U., Crimi, M., & Andreescu, S. (2023). Current and emerging analytical techniques for the determination of PFAS in environmental samples. Trends in Environmental Analytical Chemistry, 37 (August 2022), e00198. https://doi.org/10.1016/j.teac.2023.e00198.
5. Tang, Z. W., Shahul Hamid, F., Yusoff, I., & Chan, V. (2023). A review of PFAS research in Asia and occurrence of PFOA and PFOS in groundwater, surface water and coastal water in Asia. Groundwater for Sustainable Development, 22, 100947. https://doi.org/10.1016/J.GSD.2023.100947.
6. Wee, S. Y., & Aris, A. Z. (2023). Revisiting the "forever chemicals", PFOA and PFOS exposure in drinking water. Npj Clean Water, 6(1), 1–16. https://doi.org/10.1038/s41545-023-00274-6.

Table 1 PFAS composition according to the MCLs established by the EPA. Source: (EPA, 2024)

PFAS composition	MCLs	Final MCLG
PFOA	4.0 ppt	Zero
PFOS	4.0 ppt	Zero
PFNA, PFHxS and 'GenX Chemicals'	10.0 ppt	10 ppt
Any mixture of two or more of the following PFAS: PFNA, PFHxS, PFBS, and 'GenX Chemicals'	Hazard Index controlled < 1	Hazard Index controlled < 1