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Effective Strategies for PFAS Removal: Sorption Techniques Using Activated Carbon and Anion Exchange Resins

Hikro Kenji*

Department of Chemistry, Seoul National University, Seoul, Japan

Corresponding author: Hikro Kenji, Department of Chemistry, Seoul National University, Seoul, Japan, Email: parktinng@Seu.kr

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Description

Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) are a significant class of persistent organic pollutants that are resistant to natural degradation processes and have a widespread presence in the environment, posing potential health risks. PFAS, which are synthetic compounds, contain fully fluorinated carbon chains that make them highly stable and resistant to heat, chemicals and biodegradation. Therefore, they are widely used in various industrial and consumer products, including firefighting foams, water-resistant textiles, nonstick coatings and food packaging products. However, the elevated levels of PFAS in the air, water, soil and biota have been associated with adverse health effects, including developmental, immune and hormonal disruptions. Therefore, effective strategies for their removal from contaminated sources must be developed. In recent years, sorption techniques have been used for PFAS removal owing to their efficiency, cost-effectiveness and environmentally benign nature. Sorption involves the transfer of PFAS molecules from the aqueous phase to solid materials known as sorbents. Various sorbents, such as activated carbon, zeolites, polymers and biochar, have been used to adsorb PFAS from water sources. In particular, anion exchange resins and activated carbon are the most common PFAS sorbents. Activated carbon exhibits a high surface area, high porosity, an affinity for low-surface-energy materials and diverse surface chemistry, owing to which it is a preferred sorbent for many organic compounds, including PFAS. Pulverized Activated Carbon (PAC) demonstrated sorption capacities of 1.07 mmol g^{-1} for Perfluorooctane Sulfonate (PFOS) and 0.49 mmol g^{-1} for Pentadecafluorooctanoic Acid (PFOA).

Anion exchange resins

Anion exchange resins offer an alternative approach to PFAS sorption owing to their selective ion-exchange properties. The functional groups of the resin attract and exchange negatively charged PFAS present in water, effectively capturing and immobilizing them within the resin matrix. IRA910, which is a polystyrene macroporous anion exchange resin, showed sorption capacities of 2.97, 3.47, 2.79 and 3.41 mmol g^{-1} for perfluorobutanoic acid (PFBA), PFOA, PFOS and Potassium Nonafluoro-1-Butanesulfonate (PFBS), respectively. PFAS are synthetic compounds characterized by their fully fluorinated carbon chains, which impart remarkable stability and resistance to heat, chemicals and biodegradation. These properties have led to their widespread use in various industrial and consumer products, including firefighting foams, water-resistant textiles, nonstick coatings and food packaging products. Despite their beneficial properties, the persistence and mobility of PFAS in the environment have raised significant concerns. Elevated levels of PFAS have been detected in air, water, soil and biota, leading to potential adverse health effects. These effects include developmental issues, immune system disruption and hormonal imbalances, underscoring the urgent need for effective strategies to remove PFAS from contaminated sources. Sorption techniques have emerged as a promising solution for PFAS removal due to their efficiency, cost-effectiveness and environmentally benign nature. Sorption involves the transfer of PFAS molecules from the aqueous phase to solid materials known as sorbents. Various sorbents have been explored for PFAS removal, including activated carbon, zeolites, polymers and biochar. Among these, activated carbon and anion exchange resins have gained prominence as the most common and effective PFAS sorbents. Activated carbon is favored for its high surface area, high porosity and affinity for low-surface-energy materials. Its diverse surface chemistry allows it to adsorb a wide range of organic compounds, including PFAS. Studies have shown that Pulverized Activated Carbon (PAC) exhibits significant sorption capacities for PFAS compounds.

Development and optimization of sorption

For instance, PAC demonstrated sorption capacities of 1.07mmol g^{-1} for Perfluorooctane Sulfonate (PFOS) and 0.49 mmol g^{-1} for Pentadecafluorooctanoic Acid (PFOA). The high efficiency of activated carbon in PFAS removal makes it a preferred choice for water treatment applications. Anion exchange resins, on the other hand, offer an alternative approach to PFAS sorption due to their selective ion-exchange properties. These resins contain functional groups that attract and exchange negatively charged PFAS present in water, effectively capturing and immobilizing them within the resin matrix. IRA910, a polystyrene macroporous anion exchange resin, has shown impressive sorption capacities for various PFAS compounds. Specifically, IRA910 demonstrated sorption capacities of 2.97, 3.47, 2.79 and 3.41 mmol g^{-1} for Perfluorobutanoic Acid (PFBA), PFOA, PFOS and Potassium Nonafluoro-1-Butanesulfonate (PFBS), respectively. The high selectivity and efficiency of anion exchange resins make them a valuable tool in PFAS remediation efforts. The development and optimization of sorption techniques for PFAS removal continue to be a focus of research. Understanding the interactions between PFAS molecules and sorbent materials is crucial for improving the performance of these techniques. Additionally, efforts are being made to enhance the regeneration and reuse of sorbents to minimize waste and reduce operational costs. Innovations in sorbent materials, such as the development of modified activated carbon and novel anion exchange resins, hold promise for more efficient and sustainable PFAS removal processes. The widespread presence of PFAS in the environment and their associated health risks necessitate effective strategies for their removal from contaminated sources. Sorption techniques, particularly those involving activated carbon and anion exchange resins, have demonstrated significant potential in PFAS remediation. The ongoing research and development in this field aim to further enhance the efficiency, selectivity and sustainability of sorption-based PFAS removal methods. By leveraging these advancements, we can mitigate the environmental impact of PFAS and safeguard public health.