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Nano-enabled sensing of per-/poly-fluoroalkyl substances (PFAS) from aqueous systems – A review

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ABSTRACT

Per-/poly-fluoroalkyl substances (PFAS) are an emerging class of environmental contaminants used as an additive across various commodity and fire-retardant products, for their unique thermo-chemical stability, and to alter their surface properties towards selective liquid repellence. These properties also make PFAS highly persistent and mobile across various environmental compartments, leading to bioaccumulation, and causing acute ecotoxicity at all trophic levels particularly to human populations, thus increasing the need for monitoring at their repositories or usage sites. In this review, current nano-enabled methods towards PFAS sensing and its monitoring in wastewater are critically discussed and benchmarked against conventional detection methods. The discussion correlates the materials' properties to the sensitivity, responsiveness, and reproducibility of the sensing performance for nano-enabled sensors in currently explored electrochemical, spectrophotometric, colorimetric, optical, fluorometric, and biochemical with limits of detection of 1.02×10^{-6} μg/L, 2.8 μg/L, 1 μg/L, 0.13 μg/L, 6.0×10^{-5} μg/L, and 4.141×10^{-7} μg/L respectively. The cost-effectiveness of sensing platforms plays an important role in the on-site analysis success and upscalability of nano-enabled sensors. Environmental monitoring of PFAS is a step closer to PFAS remediation. Electrochemical and biosensing methods have proven to be the most reliable tools for future PFAS sensing endeavors with very promising detection limits in an aqueous matrix, short detection times, and ease of fabrication.

1. Introduction

Per-/poly-fluoroalkyl substances (PFAS), a class of persistent organic pollutants (POPs), are of growing concern due to the consequences of their release into the environment and on biomes. Structurally, PFAS are compounds wherein a substituted carbon backbone, fully or partially fluorinated, is terminated by a polar acidic functional group (Firdaus et al., 2014; Kannan, 2011). Their outstanding chemical and thermal stabilities, coupled to their near omni-phobic nature supporting repellence to most of the liquids, make them an excellent choice as additives or surfactants to alter the properties of materials. Since the 1950s, PFAS have been employed extensively in the manufacturing of commercial products such as refrigerants, aqueous fire-fighting foaming (AFFF) agents, cosmetics and insecticides formulations, and as coatings for paper, textile materials, kitchen frying pans, or electrical wires, to name a few (Wang et al., 2019).

PFAS are recalcitrant due to very stable and electronegative carbon-fluorine chains, with bond dissociation energy of 116 kcal/mol, making their degradation challenging. The surfactant and micellar properties of PFAS arising from their amphiphilic nature enable their wide range of transport, allowing for mobility across all environmental compartments of soil-sediment, air, biota, and water (Wang et al., 2017) and the pK_a

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