



Review

A critical science mapping approach on removal mechanism and pathways of per- and poly-fluoroalkyl substances (PFAS) in water and wastewater: A comprehensive review

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ABSTRACT

Perfluoroalkyl substances (PFAS) are a group of synthetic organic chemicals extensively used in consumer and industrial applications over the past decades. The current literature lacks a comprehensive review of the mechanisms and degradation pathways of long- and short-chain PFASs. The overall concentration of perfluorobutanoic acid in aquatic systems ranged from 1.15 to 6280 ng/L, while perfluorobutane sulfonic acid varied from 0.01 to 4520 ng/L. Prior to 2015, perfluorooctanoic acid (PFOA) concentrations in wastewater treatment facilities ranged from 92 to 66,000 ng/L, while levels decreased after 2015 (3–100 ng/L) as PFAS production decreased. This systematic literature review compiles the latest evidence of the mechanism and pathway degradation of emerging technologies, such as advanced oxidation processes, membrane separation, adsorption, and biological transformation of PFAS, which were reviewed comprehensively. Bibliometric assessment was performed using keyword-based search criteria, and network maps were created using VOS Viewer. Activated carbon showed >90 % elimination of long-chain PFAS. Nanofiltration and reverse osmosis membranes were observed to be effective for perfluorooctane sulfonic acid and PFOA removal, with rejection efficiencies of >99 % in aqueous matrices with different membrane materials. Pilot scale studies showed that granular activated carbon and biosolid-based biochar sorbed more than 80 % of long-chain PFAS and 19–27 % of short-chain PFAS. Short-chain precursors like fluorotelomers degrade 60–100 % more effectively with mixed microbial strain cultures. Two main challenges have been identified: (a) Operational complexity on a large scale and the transformation of toxic byproducts, and (b) Emerging technologies have certain removal effects on short-chain PFASs.

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) have emerged as a

significant concern in recent times. The global presence of PFAS was initially predicted based on the detection of perfluorooctane sulfonic acid (PFOS; chemically represented as $C_8F_{17}SO_3H$) in various wildlife

Abbreviations: 6:2 FTS, 6:2 fluorotelomer sulfonate; 8:2 FTS, 8:2 fluorotelomer sulfonate; AC, activated carbon; F-53B, chlorinated polyfluoroalkyl ether sulfonic acid; FOSA, fluorooctane sulfonamide; FTAA, fluorotelomer sulfonamide alkylamine; FTAB, fluorotelomer sulfonamide alkylbetaine; FTAL, fluorotelomer aldehyde; FTCA, fluorotelomer carboxylic acid; FTOH, fluorotelomer alcohol; FTSA, fluorotelomer sulfonic acid; FTSAS, fluorotelomer mercaptoalkyl amidosulfonate; FTUCA, fluorotelomer unsaturated carboxylic acid; GAC, granular activated carbon; Gen-X, hexafluoropropylene Oxide (HFPO) Dimer Acid; PAC, powdered activated carbon; PFAAs, perfluoroalkyl acids; PFAS, per- and polyfluoroalkyl substances; PFBA, perfluorobutanoic acid; PFBS, perfluorobutane sulfonic acid; PFCA, perfluoroalkyl carboxylic acid; PFHpA, perfluoroheptanoate; PFHxS, perfluorohexane sulfonic acid; PFNA, perfluorononaic acid; PFOA, perfluorooctanoic acid; PFOS, perfluorooctane sulfonic acid; PFPeA, perfluoropentanoic acid; PFPrA, perfluoropropionic acid; PFSA, perfluorosulfonic acid; sFTOH, fluorotelomer alcohol sulfonate.

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