Conductive and Redox-Active Molecularly Imprinted Polymer for Direct Quantification of Perfluoroalkyl Substances

Lead Investigator

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Background and Unmet Need

Per- and poly-fluoroalkyl (PFAS), also known as 'Forever Chemicals,' this class of chemicals has been a growing contaminant of concern throughout the last decade. PFAS present a significant human health risk, including an increased risk of cancer and reproductive defects.[1] Because these chemicals are extremely hydrophobic and do not naturally break down in the environment, they contaminate many of our ecosystems. Scientific models suggest that PFAS are present in 45% of the United States drinking water supply.[2] Further, studies have found that PFAS are present in the drinking water of 200 million Americans.[3]

The US Environmental Protection Agency has set maximum contaminant levels (MCLs) for six PFAS in drinking water, PFOA (4ppt)[4], PFOS (4 ppt), PFHxS (10ppt), PFNA (10ppt), HFPO-DA (10 ppt), and PFAS mixtures containing at least two or more of PFHxS, PFNA, HFPO-DA, and PFBS (hazard index of 1).[5] These new standards have fueled a strong demand for developing novel technologies to quantify and to identify PFAS at or below regulatory standards.

The current standard for detecting PFAS are liquid chromatography-triple quadrupole-tandem mass spectrometry (LC-MS/MS). This technology is expensive to obtain and operate, requires specialized operator training, and is labor and time intensive. There is a growing consensus among the scientific community that technologies for rapid PFAS detection at and below the regulatory concentration are critical but lacking.

Experts believe the demand for rapid, mobile, and economical PFAS detection will continue to grow as global governmental agencies evolve regulatory requirements on monitoring PFAS contamination.

Opportunity

Dr. Xu has developed a novel Molecularly Imprinted Polymer (MIP)-enabled electrochemical platform for rapid and direct quantification of non-electroactive PFAS at sub ng L^{-1} concentrations in water samples.[6] The technology provides a rapid ex-situ PFAS quantification solution by creating a conductive and redox-active MIP, which eliminates the need for external redox probes. The technology sensitivity exceeds the newly implemented regulatory requirements of 4 ppt. Selectivity is achieved through a "lock and key" strategy that binds to select PFAS molecules, resulting in minimal risk of false positive readings. The technology is also capable of detecting multiple PFAS's within water samples simultaneously. The reproducibility of the sensor fabrication process has been demonstrated in laboratory-scale tests. Consistent results were shown in the reusability test.

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[1] *Our Current Understanding of the Human Health and Environmental Risks of PFAS.,* EPA, n.d.
[2] *Per- and polyfluoroalkyl substances (PFAS) in United States tap water: Comparison of underserved private-well and public-supply exposures and associated health implications.*, Elsevier, June 2023.
[3] *Population-Wide Exposure to Per- and Polyfluoroalkyl Substances from Drinking Water in the United States.,* ACS Publications, October 2020.
[4] Parts per trillion (ppt)
[5] *Final PFAS National Primary Drinking Water Regulation*., Environmental Protection Agency, n.d.
[6] *Novel Conductive and Redox-Active Molecularly Imprinted Polymer for Direct Quantification of Perfluorooctanoic Acid.,* Sumbul Hafeez, Aysha Khanam, Han Cao, Brian P. Chaplin, and Wenqing Xu, Environmental Science & Technology Letters, 2024 11 (8), 871-877, DOI: 10.1021/acs.estlett.4c00557

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This proprietary MIP technology is a platform for future PFAS sensors. The technology may be integrated into a compact mobile electrochemical platform, enabling on-site sample collection and detection. Compared to the current state of the art, on-site detection of PFAS contaminants is not technically feasible. As a result, the technology platform presents the opportunity to be further developed into a first-of-its-kind field-deployable sensor to provide real-time detection of PFAS compounds while in the field.

The PFAS testing market was valued at $110 million in 2023 and is expected to grow to $217 million by 2028 at a CAGR of 14.4%. The market's growth is driven by the privatization of environmental testing services, increased investment in water resource management, and regulatory pressure from the Environmental Protection Agency.[7]

Unique Attributes

- Rapid detection and quantification of PFAS at sub ng L-1 concentrations in water
- Platform technology compatible with the development of mobile sensor apparatus.
- Economical solution to PFAS detection in varying environments.
- Direct quantification of PFAS enabled by a novel and redox-active Molecular Imprinted Polymer platform that eliminates the need for external redox probes.

Applications

A redox-active molecular imprinted polymer for the rapid ex-situ detection of PFAS contaminants within drinking water resources.

Stage of Development

Technology validated in a relevant environment (Technology Readiness Level 5) and operational prototype.

Intellectual Property

PCT Patent Application filed March 2025.

Publications

Novel Conductive and Redox-Active Molecularly Imprinted Polymer for Direct Quantification of Perfluorooctanoic Acid., Sumbul Hafeez, Aysha Khanam, Han Cao, Brian P. Chaplin, and Wenqing Xu, Environmental Science & Technology Letters, 2024 11 (8), 871-877, DOI: 10.1021/acs.estlett.4c00557

Licensing and Collaboration Opportunity

Villanova is seeking a licensee or collaborators to commercialize or to further develop the invention.

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[7] *PFAS Testing Markets*…. Markets and Markets, December 2023.