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Molecularly imprinted polymers for the detection and remediation of emerging pollutants: Strengths, limitations, and future perspectives

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Abstract

Molecularly imprinted polymers (MIPs) have emerged as highly selective, robust, and versatile materials for the detection and remediation of emerging pollutants, combining the recognition precision of biological receptors with the stability and reusability of synthetic polymers. Advances in molecular imprinting technology (MIT) have enabled tailored recognition sites capable of binding specific contaminants in complex matrices, including pharmaceuticals, endocrine disruptors, pesticides, heavy metals, and microplastics. Recent developments in multi-target MIP sensors, hybrid materials (e.g., MIP–MOF composites), and stimuli-responsive designs have expanded detection capabilities, enabling simultaneous quantification of multiple analytes in environmental samples with high sensitivity and specificity.

Green chemistry principles are increasingly integrated into MIP synthesis, employing bio-based monomers, renewable crosslinkers, deep eutectic solvents, and solvent-free polymerization methods to minimize environmental impact. Biomass-derived MIPs, biodegradable composites, and computationally guided monomer selection have contributed to more sustainable and efficient recognition platforms. Eco-friendly fabrication approaches, such as microwave-assisted polymerization and aqueous-phase imprinting, have also improved scalability and safety.

Despite remarkable laboratory performance, several challenges limit large-scale deployment, including incomplete template removal, cross-reactivity, reduced recognition in real-world samples, and the lack of standardized evaluation protocols. Furthermore, the commercial adoption of MIP-based remediation systems remains slow due to production costs, regeneration efficiency, and integration issues with continuous monitoring devices. Future research should focus on: i) coupling MIPs with multi-transduction systems (such as electrochemical, optical, and gravimetric) for real-time multi-analyte monitoring; ii) improving the imprinting process via theoretical modelling and AI-assisted design; and iii) adopting circular-economy strategies in MIP production and disposal.

By bridging the gap between laboratory innovation and field application, MIPs can play a decisive role in safeguarding environmental and public health through sustainable pollutant detection and remediation.

Keywords: Chemical sensors, Emerging pollutants' detection, Molecularly imprinted polymers, Remediation.