

Modern sample prep: Efficiency, sensitivity, sustainability.

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Introduction

A comprehensive overview of the latest advancements in microextraction techniques focuses on their application in environmental analysis. It covers innovative sorbent materials and new extraction modes, highlighting improved sensitivity and efficiency for trace pollutant detection in complex environmental matrices. These green chemistry approaches minimize solvent usage and offer more sustainable alternatives for sample preparation [1].

Significant progress has been made in solid-phase extraction (SPE) methods, specifically tailored for pharmaceutical and biomedical analysis. This includes discussions on novel sorbents like molecularly imprinted polymers and restricted-access media, alongside advancements in miniaturized SPE formats. These innovations enhance selectivity, reduce sample volume, and streamline sample preparation for complex biological samples, improving analytical performance [2].

The evolution of green liquid-liquid microextraction (LLME) techniques is explored as sustainable alternatives for analytical sample preparation. Various LLME methodologies are detailed, highlighting their advantages in terms of reduced solvent consumption, lower waste generation, and enhanced preconcentration factors. Diverse applications across different analytical fields are covered, showcasing the broad applicability and environmental benefits of these methods [3].

Recent breakthroughs in automated sample preparation technologies are summarized, specifically for clinical and forensic toxicology. This includes fully automated platforms that integrate extraction, cleanup, and injection steps, significantly reducing manual labor, improving reproducibility, and accelerating analysis times. Automation addresses the need for high-throughput, reliable, and standardized sample processing in critical analytical settings [4].

Current developments in sample preparation for quantitative proteomics are reviewed, an area critical for accurately measuring protein abundance. Improved methods for protein extraction, digestion, and peptide fractionation are discussed, emphasizing techniques that enhance reproducibility and reduce sample loss. The insights help researchers achieve more precise and comprehensive

proteomic analyses from various biological matrices [5].

Recent innovations in bioanalytical sample preparation techniques, specifically designed for mass spectrometry, are a key focus. New methods for handling diverse biological samples, including blood, urine, and tissues, are explored to improve detection limits and reduce matrix effects. Advancements in microextraction, automated systems, and material science are pushing the boundaries of sensitivity and specificity in clinical and research applications [6].

Fabric phase sorptive extraction (FPSE) is introduced as a green and efficient sample preparation method for both environmental and biological samples. The underlying principles of FPSE, its unique advantages, and its growing number of applications are detailed. This technique, utilizing functionalized fabric as a sorbent, provides a simple, robust, and cost-effective solution for isolating and concentrating analytes, aligning with sustainable analytical practices [7].

The transformative role of microfluidic platforms in streamlining sample preparation for clinical diagnostics is highlighted. These lab-on-a-chip devices enable miniaturized, integrated, and automated sample processing, from cell lysis and DNA extraction to biomarker preconcentration. Their potential to improve diagnostic speed, reduce sample volume, and facilitate point-of-care testing leads to faster and more accessible healthcare solutions [8].

Recent advancements in QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) based methods are reviewed, particularly for pesticide residue analysis in food and environmental samples. Modifications to the original QuEChERS procedure are explored, including improved sorbents and extraction solvents, to enhance its applicability to a wider range of analytes and matrix types. The technique's continued importance for efficient and reliable sample preparation in food safety and environmental monitoring is emphasized [9].

The increasing role of nanomaterials in enhancing sample preparation for the chromatographic analysis of environmental contaminants is examined. Various types of nanomaterials, such as magnetic nanoparticles, carbon nanotubes, and graphene, are covered, highlighting their unique properties like high surface area and tunable selectivity. These materials significantly improve extraction

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efficiency and detection limits for trace pollutants in complex environmental matrices, offering more powerful analytical tools [10].

Conclusion

Recent advancements in sample preparation techniques are transforming analytical chemistry by offering more efficient, sensitive, and sustainable methods across diverse fields. Microextraction techniques, including green liquid-liquid microextraction and fabric phase sorptive extraction, are improving environmental analysis and biological sample processing by minimizing solvent use and enhancing preconcentration. Solid-phase extraction methods have seen progress with novel sorbents like molecularly imprinted polymers, optimizing pharmaceutical and biomedical analysis through increased selectivity and reduced sample volumes. Automation is playing a significant role, particularly in clinical and forensic toxicology, where integrated platforms streamline extraction and cleanup, leading to improved reproducibility and faster analysis times. These automated systems are also crucial in bioanalytical sample preparation for mass spectrometry, pushing the boundaries of sensitivity and specificity in complex biological matrices like blood, urine, and tissues. Further innovations include microfluidic platforms for clinical diagnostics, which offer miniaturized and integrated processing, accelerating diagnostic speed and enabling point-of-care testing. The development of QuEChERS-based methods continues to enhance pesticide residue analysis in food and environmental samples, while the integration of nanomaterials like magnetic nanoparticles and graphene in sample preparation significantly boosts extraction efficiency and detection limits for environmental contaminants. Overall, these innovations collectively address critical needs for improved analytical performance, environmental sustainability, and high-throughput capabilities in modern laboratories.

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