Multidetection Field-Flow Fractionation for Polymer and Nanoparticle Analysis: Application to Injectable Malaria Drug Delivery Systems

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Advanced polymeric and soft-matter systems require analytical approaches capable of resolving complex distributions in molar mass, size, architecture, composition, and supramolecular organization. This is particularly relevant for functional polymers, hybrid materials, and nanoparticle-containing systems, where classical bulk characterization often provides insufficient information on heterogeneity and structure-property relationships. Our recent activities focus on the development and application of advanced polymer separation methods, with particular emphasis on Field-Flow Fractionation coupled to multiple detection systems and high-temperature separation techniques.

Asymmetric Flow Field-Flow Fractionation (AF4) is a gentle and versatile separation platform for macromolecules, colloids, nanoparticles, and polymer-based assemblies in solution. Combined with online multidetection, including light scattering, refractive index, UV-Vis, fluorescence, and structural scattering methods, AF4 provides insight into size distributions, molar mass, aggregation, morphology, and component localization. Recent online coupling of AF4 with SAXS and SANS further extends the accessible structural information. Complementarily, high-temperature separation approaches are indispensable for technically relevant polymers with limited solubility under ambient conditions.

The potential of these methodologies will be illustrated using lipid nanoparticles for the controlled delivery of antimalarial drugs from injectable hydrogels. In this project, lipid nanoparticles based on natural components, such as carnauba wax and red palm oil, are embedded in a biocompatible glycosaminoglycan-poly(ethylene oxide) hydrogel, forming an in situ self-assembling scaffold via Michael-type addition reaction. A central analytical challenge is the elucidation of nanoparticle stability, distribution, morphology, drug encapsulation, and release behavior from the hydrogel matrix.

To address these questions, a comprehensive strategy integrating Dynamic Light Scattering, Cryo-TEM, SAXS/WAXS, and AF4 coupled to multiple online detectors is employed.[1,2] Online UV-Vis and fluorescence detection allow drug quantification and localization, while AF4-based multidetection provides detailed information on particle populations and release processes. This example demonstrates how advanced polymer separation and multidetection techniques support the molecular and colloidal understanding of complex biomedical materials and their rational development toward therapeutic applications.

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2. E. Bittrich, S. Boye, Z. Van Niekerk, Z. Stanvliet, A. Porfetye, F. Herranz-Trillo, H. Bolinsson, S. Gaydarova, C. Tzachev, A. Martel, L. Nilsson, R. Schweins, A. Lederer, Small Methods 2026 DOI:10.1002/smtd.70639.