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Enhancing SpentDialysate Regeneration: The Role of Magnetic Nanoplatforms and Advanced Membranes

ABSTRACT

Hemodialysis remains the principal treatment for end-stage renal disease, but its high consumption of ultrapure water and dialysate creates major environmental and economic burdens. This work presents a more advanced and sustainable dialysateregeneration strategy based on the integration of cellulose acetate/silica monophasic hybrid membranes with superparamagnetic iron oxide nanoparticles functionalized by silica. The proposed system combines membrane selectivity, nanoparticle adsorption, and magnetic recovery to improve urea removal while enabling dialysate reuse.

The monophasic hybrid membranes were prepared by a sol–gel assisted phase inversion route, producing asymmetric structures with tunable porosity and mechanical strength. Structural characterization by ATR-FTIR and SEM confirmed the successful formation of homogeneous CA/SiO_2 membranes. In parallel, core-shell nanoparticle were synthesized by co-precipitation followed by silica-based surface functionalization, yielding uniform core–shell particles with good colloidal stability and superparamagnetic behavior. This coating enhanced dispersion and surface functionality while preserving magnetic retrievability.

The current stage of the project focuses on validating the integrated membrane–nanoparticle regeneration platform under conditions relevant to dialysis applications. Experimental investigations have demonstrated the compatibility of the membrane and magnetic nanomaterials, the efficient recovery of nanoparticles after the adsorption stage, and the operational feasibility of the sequential adsorption–magnetic separation–membrane filtration process. Ongoing studies are evaluating the overall regeneration performance of the complete system, and a comprehensive assessment will be reported in future publications.

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This work represents a significant step beyond our previous membrane-based approach by introducing a recoverable and integrated nanoplatform designed for sustainable dialysate regeneration. The proposed strategy provides a scalable foundation for next-generation hemodialysis technologies while supporting reduced resource consumption and improved process sustainability.

Keywords: Spent dialysate regeneration, SPIONS, core-shell silica nanoparticles, adsorption, Separation technology.

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BIOGRAPHY

Fahimeh Zare is a PhD in Chemical Engineering and researcher specializing in membrane technology, nanoparticle synthesis, and porous thin film characterization. She contributes to the HORIZON PHOTONGATE project, focusing on advanced photonic multi-sensing systems. Fahimeh has presented at various international conferences and published four peer-reviewed articles, with another under review. Her work appears in top journals like Membranes, Sensors, and Hydrogen Energy. She received several honors, including the BIC France-Portugal scholarship. Her research targets advanced membrane materials, uremic toxin removal, SPIONS and core-shell Nanoparticles, and hydrogen production technologies, aiming to drive innovation in separation science and sustainable energy through collaborative, high-impact research.