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Book Review
pH Responsive Membranes: Biomedical Applications

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ABSTRACT

Biomedical science is a broad interdisciplinary field that integrates biology and medicine, aiming to improve diagnosis, treatment, and disease prevention. Membrane technology plays a significant role in this domain, particularly in drug delivery, hemodialysis, chemical sensing, and the purification of pharmaceutical products. These include the recovery of antibodies and enzymes, protein concentration, and the reclamation of ultrapure water for processing and cleaning. As highlighted by the authors, pH-responsive membranes are typically composed of two main polymer groups: carboxyl-containing polyacids and pyridine-based polybases. These polymers swell and ionize differently depending on the surrounding pH, resulting in tunable permeability and selectivity. This book offers a novel consolidation of responsive membrane principles with a focus on biomedical applications. References span both foundational and emerging research, providing a balanced representation of state-of-the-art developments. It bridges theoretical transport models and real-world use cases, offering a valuable reference for material selection, design, and functional optimisation of pH-responsive membranes.

The book is structured into two major sections. The first section covers the fundamentals of responsive membranes, including working principles, solute transport theories, fabrication and modification methods, materials used, and membrane configurations. Chapter 1 introduces various responsive membrane types and fabrication techniques. Chapter 2 elucidates the mathematical models governing solute transport, including Darcy's Law and Knudsen flow, and discusses how chemical potential and pH influence surface charge, swelling, pore size, wettability, and overall separation performance. Chapters 3 and 4 focus on fabrication methods such as blending, surface grafting, and pore filling, using configurations like flat sheets and hollow fibers. A wide range of pH-responsive materials are reviewed, including polyacrylic acid derivatives, zwitterionic polymers, polyelectrolytes, and emerging hydrogels.

The second section highlights applications in biomedical industries and suggests improvements for future implementation. Chapter 5 comprehensively reviews uses in drug delivery, hemodialysis, enzyme and antibody production, chemical sensing, and selective ion transport. For instance, pH-responsive membranes in IVR reservoirs enable triggered nanoparticle release via morphological changes and altered electrostatic interactions. Hydrogel-based membranes are shown to swell or shrink in response to pH, enhancing controlled drug delivery. In hemodialysis, pH-responsive membranes aim to reject urea and creatinine while improving antifouling and

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hemocompatibility. These enhancements are achieved via surface modification with poly(lactic acid)-block copolymers or blending with additives like poly(ethylene oxide) and acid-functionalized multiwalled carbon nanotubes. The membranes also show improved selectivity for neutral solutes (e.g., glucose) over salts.

While the book presents a comprehensive overview of pH-responsive membranes, further discussion on how these systems compare with conventional pressure-driven membranes would enhance the reader's understanding. Key technical challenges such as membrane fouling, antimicrobial resistance, and the permeability–selectivity trade-off remain underexplored in the current text and warrant deeper discussion [1]. Chapter 6 briefly addresses membrane fouling and discusses self-cleaning and temperature-responsive membranes that desorb bovine serum albumin by changing hydrophilicity. These could be developed into dual- or multi-responsive membranes with enhanced functionality [2]. Additionally, recent studies report mechanical limitations of single-network interpenetrating polymer network (IPN) hydrogels, which can be improved by introducing a second network to enhance strength and impart self-healing properties [3]. The chapter also discusses the potential of single-gating membranes for solute fractionation via pH-triggered adsorption/desorption and highlights a shift from flat-sheet to hollow-fiber configurations due to higher surface-area-to-volume ratios. However, a review of alternative configurations such as electrospun membranes would have been beneficial [4].

The transition of pH-responsive membranes from laboratory research to clinical and industrial use remains limited. While numerous studies have explored their development and functionality at the bench scale, only a few applications, such as haemodialysis and drug delivery, have successfully reached widespread implementation. More advanced uses, including antibody and enzyme production, chemical sensing and separation, are still confined to laboratory or pilot trials. Regulatory pathways for biomedical deployment require extensive validation of long-term biocompatibility, performance consistency, and safety. These requirements become more stringent when nanocomposite membranes are involved, due to the potential risk of nanomaterial leaching and contamination of pharmaceutical-grade products. Additionally, the complexity in synthesising of pH-responsive polymers, particularly when scaling up production, presents a significant barrier. For broader adoption, it is essential to establish cost-effective, standardized manufacturing methods that ensure both reproducibility and compliance with regulatory standards. Future research should address the mechanical robustness and long-term stability of pH-responsive membranes, particularly in dynamic biological environments. The integration of multi-responsive functionalities, scale-up fabrication, and alignment with biomedical regulatory standards will be critical to advancing clinical applications.

In conclusion, this book is a valuable resource for researchers and professionals working in membrane science, biomaterials, and biomedical engineering. It provides a strong foundation on the design and application of pH-responsive membranes, particularly for those exploring smart material interfaces for healthcare and pharmaceutical industries.

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