



Fabrication Techniques and Emerging Applications of Hydrogels

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Description & Coverage

Description:

Hydrogels have gained attention in recent years due to their physical properties and biocompatibility. Advancements in fabrication techniques have expanded the potential of hydrogels in various scientific and industrial domains. These innovations improve the structural and functional versatility of hydrogels while catalyzing their integration into emerging applications, including medical engineering, drug delivery systems, robotics, and wearable technology. Further exploration of the latest developments in hydrogel fabrication technologies may reveal their growing role in the future of biomedical and engineering solutions.

Fabrication Techniques and Emerging Applications of Hydrogels explores the field of functional materials and materials chemistry. It examines emerging opportunities available in the application of hydrogels and soft materials. This book covers topics such as electrochemistry, mechanical engineering, and sensor devices, and is a useful resource for engineers, chemists, manufacturers, academicians, researchers, and environmental scientists.

Coverage:

The many academic areas covered in this publication include, but are not limited to:

- 3D/4D Printing
- Additive Manufacturing
- Bioelectronics
- Biomedicine
- Chemical Engineering
- Electrochemistry
- Environmental Science
- Fabrication Techniques
- Hydrogels
- Machine Learning
- Materials Science
- Mechanical Engineering
- Sensor Devices

Table of Contents

Please note that this book is currently in development and this table of contents is tentative. Chapter authors can make adjustments to their individual submissions in the eEditorial Discovery® system if they notice any discrepancies.

Chapter 1

Introduction to Hydrogels: Introduction to Hydrogels

Onome Ejeromedoghene, Moses Kumi

Hydrogels are 3D polymer networks that absorb large fluid volumes, mimicking soft tissues. Their hydrophilicity comes from -OH, -COOH, or -NH₂ groups, enabling tunable swelling. Evolving from simple absorbents to stimuli-responsive systems, hydrogels are classified by origin (natural/synthetic/hybrid), crosslinking, and environmental sensitivity. These properties make them ideal for biomedicine, drug delivery, tissue engineering, and flexible electronics due to their biocompatibility and adaptability. Current research focuses on smart hydrogels and nanotechnology integration, driving innovations in science and technology.

Chapter 2

Hydrogels Processing Techniques

Aqib Mehmood, Irum Fatima, Muhammad Hamza

Hydrogels have emerged as an adaptable class of biomaterials because of their significant applications in the biomedical field, environmental remediation, agriculture, cosmetics, and food industry. Over the years, numerous methods have been reported to have control over the properties of hydrogels. This section follows the physical and chemical processes of crosslinking polymers, hybrid strategies, and polymerization techniques that have revolutionized the processing of hydrogels in numerous ways. This chapter also highlights the role of constituent molecules, including monomers, cross-linkers, and nanocomposite materials in synthesizing hydrogels for specific applications, such as stimuli sensitivity, swellability, biodegradability, biocompatibility, and mechanical strength. The biocompatible and stability challenges have also been addressed as a significant hurdle for their scalability.

Chapter 3

Solvent and Solventless Hydrogels

Ahmed Omoniye, Adefarati Olorunboba, Omolade Adeniji, Samuel Ojo, Victor Ebiekpe, Noela Igwemmar, Sunday Kolawole

Conventional organic solvents have been widely employed in hydrogel fabrication, but their environmental and health concerns have motivated the search for alternative solvent systems. Ionic liquids have emerged as promising substitutes, offering low volatility, high thermal stability, and improved biocompatibility. Deep eutectic solvents, formed by combining components with unique solvent properties, exhibit low toxicity, biodegradability, and potential for sustainable manufacturing. Surfactants play crucial role in emulsion-based methods, influencing hydrogel structure and properties. Solventless hydrogels, eliminating the need for solvents, provide simplified fabrication processes, reduced environmental impact, and improved biocompatibility. This chapter provides an overview of these solvent systems, discussing their advantages, limitations, and applications in hydrogel synthesis. Understanding the diverse solvent options enables the development of advanced hydrogel materials tailored for various fields, including biomedicine, tissue engineering, and other industrial applications.

Chapter 4

Characterization Strategies for Graphene Containing Hydrogel Systems: Techniques for Evaluating Structural Properties

Masooma Nazar, Ambavaram Vijaya Bhaskar Reddy, Aqeel Ahmad, Syed Muhammad Shakil Hussain, Othman Charles S Al-Hamouz, Muhammad Moniruzzaman

Graphene-based hydrogels comprising graphene, graphene oxide or reduced graphene oxide form three-dimensional polymeric networks with high strength, tunable permeability and large surface area. These properties make them suitable for applications in biomedical, soft electronics and water purification. Characterization of GBHs is vital to understand their structure property relationships. FT-IR and Raman spectroscopy reveals the chemical composition, XRD assesses the crystallinity, and SEM/TEM provides morphological insights. On other hand, TGA and DSC evaluate thermal properties, while BET analysis determines surface area, structural connectivity and pore size distribution. This chapter provides a comprehensive overview on GBHs, highlighting their multifunctionality across biomedical, environmental and industrial domains. It emphasizes the structure-property-performance relationship and integrates advanced characterization techniques to align with real-world applications.

Chapter 5

Functional Properties of Hydrogels

Muzammal Hussain, Abbas Faheem, Arooba Amir, Munir Hussain, Aqib Mehmood

Hydrogels have emerged as a focal material in modern science, finding applications across various fields, including medical treatments, industrial processes, and optical devices. Their behavior varies significantly depending on the surrounding medium, making them versatile for a range of applications. In this chapter, we discuss key applications and properties of hydrogels, such as self-crosslinking wound dressings, diabetic wound care, and natural polymer-based formulations. Additionally, we explore their self-adaptive wound healing capabilities and their potential in biomedical advancements. Hydrogels are increasingly recognized as promising materials, particularly in the medical field, due to their biocompatibility, tunable properties, and multifunctionality. Given their adaptability and effectiveness, they hold significant potential for future advancements across various disciplines, making them a crucial material for ongoing research and development.

Chapter 6

The Electrochemistry and Electrochemical Properties of Hydrogel-Based Composites

Ibukun Shotonwa, Rilwan Kareem, Mofayo Agunbiade, Kenechukwu Okonkwo, Abisola Akinwuyi, David Ayeni, Babatunde Dawodu, Martin Agosu, Abimbola Afolabi, Adebayo Oduwole

Hydrogel-based composites possess unique electrochemical properties that have substantially triggered the development of efficient, cost-effective, and sustainable energy storage systems. As electrochemical storage technologies like batteries and supercapacitors become central to portable power solutions, there is a growing focus on optimizing performance parameters such as specific energy and power density. Ongoing efforts aim to design advanced materials that outperform existing systems while addressing environmental concerns associated with electronic waste. Key features of hydrogel-based composites—ranging from long-term stability, high proton conductivity, to enhanced energy storage via redox and electrostatic mechanisms—stem from the use of sustainable biomaterials like chitosan and activated carbon. Their flexibility, stretchability, and biocompatibility also make them ideal for wearable electronics and biomedical applications. This chapter explores various hydrogel-based composites, their electrochemical behavior, and the mechanisms driving their performances.

Chapter 7

Super Porous Hydrogels

Irum Fatima, Humaira Razzaq, Shazia Naheed, Zobiya Asghar

To overcome the hindrance in the rate of swelling and mechanical strength of hydrogels for different targeted applications that require rapid fluid uptake. Superporous hydrogels have emerged as a new class of materials to hinder these challenges. This chapter will explore the fabrication of SPHs, and various synthetic techniques such as porosity, phase separation, cross-linking, and gas-blowing methods. The main features of SPHs are high porosity, rapid rate of swelling, higher adsorption capacity, stimuli-responsive behavior to the external environment, biocompatibility, high surface area, and enhanced mass transfer. The SPHs are categorized into three generations: conventional SPHs, SPH composites, and SPH hybrids, with improved mechanical properties and functionalities across various generations. Various applications of SPHs in biotechnology and biomedical engineering are discussed. SPHs have a lot of potential to revolutionize different fields due to their unique properties and tailored functionalities.

Chapter 8

Stimuli-Responsive Intelligent Hydrogels

Muzammal Hussain, Aneela Tabasum, Tahira Amir, Khurram Shehzad

Recent progress in materials science has led to the emergence of stimuli-responsive intelligent hydrogels, which have gained significant interest due to their unique properties and wide-ranging applications. These hydrogels undergo reversible changes in physical or chemical properties when exposed to external stimuli like temperature, pH, light, electric fields, and biomolecules. Their potential spans biomedical engineering, drug delivery, soft robotics, and environmental sensing. This paper explores their synthesis, properties, and applications. Various stimuli can trigger hydrogel responsiveness, with the choice depending on the application. We discuss methods for incorporating stimuli-responsive elements, including physical entrapment, covalent attachment, and self-assembly. Fabrication techniques such as physical and chemical crosslinking are examined, along with the importance of structure-property relationships in designing precise, responsive hydrogels.

Chapter 9

INNOVATIVE TECHNIQUES IN HYDROGEL BASED SUNSCREEN FABRICATION AND ITS APPLICATION IN HEALTHCARE: Hydrogel, Sunscreen, Fabrication techniques

BRINDHA DEVI PARTHIBAN, Gokul V, Ivo Romauld S, Sudha R, Manjunathan J

The biocompatibility, high water retention, and controlled-release characteristics of hydrogels three-dimensional networks of hydrophilic polymers have made attractive carriers for sunscreen compositions. The Physical, chemical, radiation-induced, enzyme-assisted, electrospinning, and cryogelation are some of the manufacturing methods for hydrogel-based sunscreens that are examined in this review. Incorporating the hydrogels into sunscreen formulations improves skin hydration, increases the effectiveness of UV protection, and prolongs the stability of active components, such as chemical (oxybenzone, avobenzone) and physical (ZnO, TiO₂, Iron oxide) UV filters. Moreover, hydrogels contains organic antioxidants like betalains and anthocyanins, which prevents from photaging and oxidative stress. Hybrid formulations maximizes these bioactive chemicals' bioavailability and photostability including hydrogel sunscreens loaded with nanoliposomes.

Chapter 10

Synthesis and application of hydrogels of insect origin

Victor Enwemiwe, Eric Esiwo, Chioma Ojianwuna

Insect hydrogels like other hydrogels are versatile, three-dimensional polymeric networks with significant water-retention capacity, making them valuable in biomedical, agricultural, and environmental applications. This book review explores the techniques for synthesis, and multifaceted applications of insect-derived hydrogels, emphasizing their sustainability, biocompatibility, and functionality. Insects such as darkling beetles/super worm (*Zophobas morio*), black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*), large brown cicada (*Graptopsaltria nigrofuscata*), wingless flightless cockroach (*Eupolyphaga sinensis*), silk worm (*Antheraea assama*), silk worm (*Bombyx mori*), and many others serve as point source for hydrogel production. Chitosan, silk fibroin, and hemolymph proteins extracted are transformed into hydrogels via physical, ionic, enzymatic, and chemical crosslinking into valid hydrogels for diverse applications in novel food and feed, drivers for drug delivery, pesticide delivery, drinkers for insects, tissue, skin, bone and organ regeneration and more.

Chapter 11

Biomedical Prospects of Hydrogels: Chapter 06

Muzammal Hussain, Aqib Mehmood, Zaheer Ahmad, Munir Hussain, Muhammad Ajmal

Hydrogels have revolutionized biomedical applications, evolving from simple water-absorbing materials to multifunctional drug delivery systems. This section highlights their role in drug delivery, wound care, and therapeutic interventions. Their 3D network enables localized and sustained drug release, enhancing efficacy while reducing side effects. pH-sensitive hydrogels facilitate targeted gastrointestinal delivery, while thermosensitive types are effective for nasal and transdermal administration. In ophthalmology, hydrogels improve drug retention, and their ability to bypass the blood-brain barrier makes them a key research focus. Incorporating nanoparticles like silver, zinc oxide, or copper oxide enhances antimicrobial properties. Despite their potential, challenges such as scalability, stability, and precise drug release hinder clinical adaptation. However, advancements in nanoscale hydrogels, smart materials, and innovative fabrication techniques like 3D printing and microfluidics can improve drug loading and controlled release, driving future biomedical breakthroughs.

Chapter 12

Super-absorbent hydrogels for environmental remediation

Peter Oladoye, Elizabeth Omotola, Ivan Oyeye, Mayowa Oladipo, Wycliffe Wanyonyi

The removal of water and wastewater contaminants by adsorptive means has been shown to be very promising. Amongst different adsorbent materials, hydrogels have been found to be a good tool for eliminating both inorganic and organic toxic chemical substances from water and wastewater, because of swelling characteristics, bio-compatibility, non-toxicity, re-usability and high functionalities. From previous studies, it has been shown that hydrogels can be re-used and regenerated for up to 5 times, with only about 10-15% adsorption capacity loss. This chapter focuses on the viability of hydrogels and its modified forms for the treatment of water and wastewater that contains micro-pollutants like pharmaceuticals, pesticides, dyes and heavy metals. Specifically, the mechanisms of interaction/uptake, adsorption isotherm modelling, adsorption capacities and regeneration potentials of (modified) hydrogels for these selected water contaminants shall be discussed.

Chapter 13

Catalytic Hydrogels and Hydrogel-Based Composites: Applications and Innovations

Irum Fatima, Abbas Faheem, Sana Javaid, Gul E Nayyab

Catalytic hydrogels represent a groundbreaking class of materials that integrate the unique properties of hydrogels with catalytic functionality, offering transformative solutions across environmental remediation, biotechnology, and industrial processes. This chapter highlights the synthesis and utilization of hydrogel-nanoparticle composites, demonstrating their efficacy in pollutant degradation, energy conversion, and chemical synthesis. Photocatalytic hydrogels,