EMERGING MATERIALS AND TECHNOLOGIES

Nanomaterials for Water Treatment and Remediation

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Preface

Wastewater management is one of the major challenges across the world. Various chemical and biological methods of treatment have been developed to treat contaminated water. New materials with intriguing physical and chemical properties provide opportunities to address these challenges. Nanomaterials have a large surface area to volume ratio, high surface reactivity (e.g., catalytic activity), and increased multifunctionality widely used to remove contaminants from surface water and groundwater contaminated with organic/inorganic pollutants via advanced oxidation and chemical reduction, sorption, complexation, (co)precipitation, or membrane filtration. Consequently, nanomaterials have been modified or hybridized with one or more nanomaterials to achieve multifunctionality by tuning size, morphology, dimensionality, surface properties, etc. The nanocomposites of various inorganic nanoparticles with organic material have also been proven effective in removing the various impurities from contaminated water. The major pollutants, chemical pesticides, pharmaceutical wastes, fertilizers, heavy metal ions, dyes, paints and refinery waste, sugar mills textiles fibers contaminated the major volume of drinking water on the Earth's surface. In this volume, we compile up-to-date information on the various nanomaterials-based techniques used to treat polluted water.

This book primarily focuses on the recent developments of the rational design, synthesis of advanced nanomaterials and their applications for water treatment and remediation through various techniques such as adsorption, advanced oxidation process, chemical oxidation and reduction reactions, membrane-based separation, and synergistic multifunctional all-in-one nanodevices. It includes (i) rational design of nanoporous materials with tunable pore structure; (ii) fabrication of nanomaterials by surface chemistry engineering; (iii) role of nanomaterials assisted oxidation and reduction processes; (iv) design of nanomaterial supported membrane-based separation; (v) multifunctional nanomaterials for water treatment. This volume also comprehensively discusses the types of nanomaterials and their interfacial modification effect in removal, absorption and degradation features, and the effect of various factors that could influence the mechanism, capacity, and stability of nanomaterials.

To this end, the book consists of 14 chapters that reflect the progression from introductory to focused topics. **Chapter 1** introduces the fundamentals of various water treatment techniques using nanomaterials. Starting with basic water treatment methods, the principles of adsorption, filtration, coagulation, flocculation, photocatalytic degradation, ozonation, chemical oxidation reactions, and reverse osmosis using membranes are reviewed. **Chapter 2** presents the synthesis of heterostructures, modification of semiconductor interface using co-catalysts, photodegradation of antibiotics and other organic matter using visible-light-active semiconductors. In **Chapter 3,** Akhundi and Habibi-Yangjeh summarized the latest progress in constructing g-C_3N_4-based nanocomposites and their employment for the degradation of organic pollutants. They provide an overview of advancements, existing challenges, and opportunities for future development. **Chapter 4** highlights the applications of 2D materials for advanced membrane fabrication and photocatalytic treatment of

pollutants and microorganisms. Recent advances in the fabrication of thin-film composite-based membranes using 2D materials such as graphene, graphene oxide, MXenes, transition metal dichalcogenides, photo-catalytically active 2D materials (g-C_3N_4, iron oxide, manganese oxide, metal oxyhalide, boron nitride) for water purification and separation of textile dyes, metal cations, heavy metals and various pharmaceutical products are discussed in detail. The next chapter (**Chapter 5**) presents several advancements made in aspect of TiO_2 based nanomaterials for applications in water treatment and pollutant remediation. Several methods including modifying the electronic band structure of TiO_2 using different techniques such as self-doping, metal/non-metal doping, co-doping, coupling with a narrow band gap semiconductor, different surface modifications, sensitization by metal complexes dyes or organic and capping with other semiconductor or metal nanoparticles are discussed for wastewater treatment. **Chapter 6** describes the extensive research on nanoparticles for heavy metal remediation. They extensively discuss the removal of heavy metals like arsenic (As), cadmium (Cd), chromium (Cr), etc. and the mechanism behind the pollutant clean-up along with the use of various advanced characterization techniques. The reusability, metal recovery from waste effluents, prospects, and current challenges are also discussed. **Chapter 7** introduces photoactive polymers for organic pollutants oxidation and heavy metals reduction, the inactivation of bacterial species, the synergistic effects obtained through the combination of inorganic semiconductors and the photoactive polymer-based membranes. A brief overview of the latest scientific advances in the development of photoactive polymer and composites to overcome the present shortcomings for fabricating visible-light-driven photocatalysis for water treatment along with their operating principles is also presented. In the following **Chapter 8**, Kowalska's group focus on plasmonic nanomaterials for wastewater treatment and water purification, including degradation of organic compounds and microorganisms, and removal of inorganic pollutants. The photocatalysts with advanced structures, such as faceted oxides and photonic crystals, and mechanisms clarifications have been discussed in detail. They include several examples of plasmonic photocatalysts, including noble metal/semiconductor and noble metal/semiconductor/semiconductor composites, which may provide an efficient approach for removing dyes from water. Suhasini and Thiagarajan demonstrate the potential of magnetic nanoparticles for wastewater remediation water through recycling and reuse as an efficient, practical, and low-cost water treatment method. **Chapter 9** reviews the fundamental theory and concepts of magnetic nanoparticle separations and integrating various nanocomposites, polymers, and layered double hydroxides for water remediation. **Chapter 10** emphasizes the various nanofiber membrane development especially using the electrospinning technique for the removal of various pollutants. They describe several factors and parameters that affected the performance of the nanofiber membranes under experimental conditions. They provide an overview of recent applications of nanofiber membranes in removing different types of hazardous pollutants in wastewater that contains heavy metal, oil, dye, and pharmaceutical pollutant and challenges and future strategies for sustainable development and applications of the nanofiber membranes in the field of wastewater treatment. In **Chapter 11**, Hassani and Khataeeb reported various forms of carbon nanomaterials (such as carbon nanotubes, graphene, reduced graphene

oxide-based materials, fullerene, activated carbon, biochar, carbon quantum dots and graphitic carbon nitride etc.) for the elimination of pharmaceuticals and personal care products by advanced oxidation processes (AOPs), including photocatalysis, sonocatalysis, Fenton and Fenton-like process, electrochemical process, sulfate radical-based AOPs, and hybrid AOPs by the aid of carbon nanomaterials. **Chapter 12** highlights the recent advances in the use of metal–organic frameworks (MOFs) and their derivatives for the efficient removal of contaminants in wastewater. In particular, photocatalysis, sulfate radical-based advanced oxidation process, heavy metals and organic pollutants removal, and MOFs-mixed matrix membranes strategies are detailed in the discussion. They present an overview of the synthesis, components, and secondary building units of MOFs together with MOF-derived materials and the interaction mechanisms between these frameworks and the contaminants. In **Chapter 13**, Yang and Que's group reviews the progress of Low-dimensional metal chalcogenide nanomaterials for photocatalytic water treatment and remediation. They demonstrate that properties of these materials can be adjusted by the degree of quantum confinement in 0D quantum dots, 1D nanorods and 2D nanoplatelets, by material composition, and by forming heterostructures. This chapter summarized the fundamental photocatalytic mechanism insight into the exciton and carrier properties and their dependences on the dimensionality and chemical composition in metal chalcogenide nanomaterials. In **Chapter 14**, Samsudin and Sufian emphasized a panorama of the recent advances related to the fabrication and construction of emerging semiconductor photocatalysts for the treatment of antibiotic residues. They describe the fundamental principles of the advanced oxidation process, semiconductor photocatalyst, the degradation pathways of antibiotics, and invigorating perspectives on the future directions. A comprehensive understanding of the engineering of advanced nanomaterials, fundamentals, challenges, and applications offers a useful guide for a broad readership in various fields of catalysis, material sciences, environment, and energy to find the latest information. This book, titled *Nanomaterials for Water Treatment and Remediation*, comprises 14 high-quality chapters written by 50 experts from 13 countries. I would like to thank all the contributors. We owe special thanks to individual authors for their excellent chapters. We would also like to express my sincere gratitude to the publisher CRC and to the team of Dr. Allison Shatkin (Senior Publisher), Prof. Boris I. Kharissov, Gabrielle Vernachio and others involved in the successful production of this book.

Editors

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Aziz Habibi-Yangjeh, Ph.D., earned a Ph.D. in physical chemistry at the Sharif University of Technology, Tehran, Iran, in 2001. He is a full professor of physical chemistry at the University of Mohaghegh Ardabili, Ardabil, Iran. His research interests include the preparation of different heterogeneous visible-light-driven photocatalysts based on zinc oxide (ZnO), titanium dioxide (TiO_2), and graphitic carbon nitride (g-C_3N_4) and their applications in different fields, especially wastewater decontamination and photofixation of nitrogen. He has published more than 220 JCR papers, including seven reviews and nine highly cited papers. His h-index is 50. Moreover, he is on the editorial board of three international journals. He contributed three book chapters in the field of photocatalysis. He has supervised more than 35 MSc and Ph.D. students in physical chemistry.

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