Milestones in Powerful Adsorbents of Heavy-Metal Ions

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Edited by

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FOREWORD

Environmental materials science encompasses the molecular design, preparation, properties, application, recycling, and other aspects of materials, and is a multidisciplinary field involving materials science, environmental science, chemistry, and biology. This book focuses on the use of materials science for environmental remediation, specifically the design and development of powerful adsorbent materials for the removal of heavy metal ions. Topics covered include the concept and theoretical framework of environmental purifying materials, as well as characterization, research methods, applications, and recent advances in the field.

The removal of toxic heavy metal ions from contaminated environments remains a global challenge, and adsorption is an efficient and energy-saving technology for addressing this problem, especially at low concentrations. However, the facile and sustainable preparation of ion-adsorbing materials with ideal features such as powerful adsorbability, environmental benignness, and high cost-efficiency is still a great challenge. The adsorbent materials discussed in this book meet these requirements. They are based on polymers with multiple adsorbing groups, such as amino, imino, sulfonic, and hydroxyl groups, and were synthesized using a cleaner oxidative polymerization process of aniline and its derivatives in pure water. The book also includes advanced adsorbents based on other organic polymers and inorganic materials, allowing for a comprehensive comparison of their adsorption performance. The performance of these adsorbents has been systematically optimized concerning comonomer ratios, group densities, ion species, and adsorption conditions.

This book is a comprehensive compendium of global research on powerful adsorbents for the removal of several typical heavy metal ions. It comprises 23 chapters that elaborate on the new academic thought and concepts of molecular design, cleaner preparation, performance optimization, and vital applications of macromolecular adsorbents with many amino, imino, sulfonic, and hydroxyl groups that can powerfully or reversibly adsorb heavy-metal ions over most nutritious metal ions.

The main purpose of this book is to enable readers to understand, master, and even apply the fundamental concepts, theory, and cutting-edge research methods of adsorbing materials systematically and comprehensively. It can serve as a research monograph, handbook, and textbook for undergraduates, as well as M.S. and Ph.D. students in environmental science, materials science, chemistry, and related fields.

As a milestone in the historic development of advanced adsorbents mainly based on organic polymers, this book can also serve as a professional reference work for researchers, developers, engineers, managers, and educators in the field of environmental materials science and technology.

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PREFACE AND ACKNOWLEDGEMENTS

The extensive and large-scale industrial use of heavy metals has led to a global disaster of industrial wastewater, severely polluting the ecological environment, and posing a threat to the safety of humans, animals, and plants. Effective remediation of the water environment is urgently required to address the increasing challenge of heavy metal pollution. To improve the resources available to researchers, developers, and managers, we have compiled global information regarding the latest developments in various adsorbents for heavy metal ions in aqueous solutions. This book is divided into five parts and 23 chapters, which include an introduction and research background, reversible adsorption and desorption of lead ions onto poly(phenylenediamine), redox sorption and recovery of silver ions onto amino compounds and polymers, redox sorption and recovery of mercury ions onto aniline derivative polymers, and selective adsorption of heavy metal ions onto aromatic diamine polymers and longan shell.

The introductory chapters outline the global problem and impact of heavy metal pollution and the challenges associated with their efficient remediation and removal. The subsequent chapters provide detailed information on the molecular design and characteristics of specific types of advanced adsorbents that are most prevalent worldwide.

This book comprehensively and systematically demonstrates the new scientific thought and concept of the molecular design, cleaner preparation, performance optimization, and vital application of macromolecular materials-based adsorbents with various amino, imino, sulfonic, hydroxyl, ester, and methoxy groups that can powerfully, reversibly, or selectively adsorb heavy-metal ions and noble metal ions, including Pb(II), Hg(II),

Ag(I), and Au(III), over most nutritious metal ions, such as Na(I), Ca(II), Mg(II), and K(I). The various polymer particles obtained demonstrate selective adsorbability towards heavy-metal ions over most nutritious ions. The highest adsorption capacity is 2771.8 mg/g for Au(III), 2034 mg/g for Ag(I), 2063 mg/g for Hg(II), and 2400 mg/g for Pb(II), while the fastest adsorption equilibrium can be reached within 3 minutes for Pb(II), achieving the highest Pb(II) adsorption rate of 8491.7 mg/(g.min). The sorption rate and partition coefficient of Hg(II) are 763.3 mg/(g.min) and 5040 mg/(g.μM), respectively.

This approach differs from other adsorbents reported because the preparation of other adsorbents, such as activated carbon and -SH-based polymers, is an environmentally harmful process that requires high-temperature carbonization and extremely toxic and foul-smelling thiol reagents. Their adsorption performance is still relatively lower than that of the macromolecular materials-based adsorbents designed and prepared in this book, resulting in low cost-efficiency and poor sustainability.

We hope that this book will be a valuable resource for both scientific researchers and environmental managers. The academic thought and engaging concept of designing and preparing powerful adsorbents presented in this book, with penetrating insight, will attract the attention of contemporary scientific researchers, environmental chemists, materials scientists and developers, R&D engineers, educationists, Ph. D./Master candidates, postdocs, and undergraduate students in the interdisciplinary field of environment and materials science and engineering.

We would like to express our sincere gratitude to all the contributors who generously gave their time and provided invaluable scientific input for this book. We recognize that many individuals faced significant challenges due to the Covid-19 pandemic, and we appreciate their dedication and resilience in contributing to this book. Particularly, we extend our thanks to the National Natural Science Foundation of China (No. 52173011) for their

support, which made it possible to satisfactorily complete this book on schedule.

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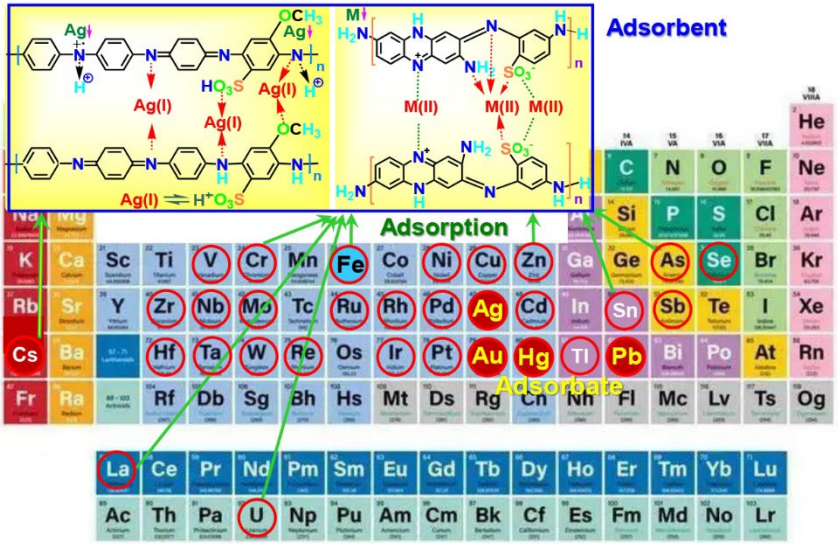
ABSTRACT

Contamination from toxic heavy-metal ions poses a significant challenge globally. Adsorption has proven to be an efficient and energy-saving technology for removing heavy metals, especially at low concentrations. However, preparing ion-adsorbing materials that have comprehensive features including powerful adsorbability, environmental benignity, and high cost-efficiency remains a challenge. The adsorbing materials discussed in this book can meet these requirements. The adsorbents are based on polymers with multiple adsorbing groups, including amino, imino, sulfonic, and hydroxyl groups, and were synthesized using a cleaner oxidative polymerization process of aniline and its derivatives in pure water. The adsorbent performance has been systematically optimized with respect to the comonomer ratio, group densities, ion species, and adsorption conditions. The polymer particles obtained demonstrate selective adsorbability towards heavy-metal ions over most nutritious ions. The highest adsorption capacity achieved is 9250 mg/g for Au(III), 2500 mg/g for Ag(I), 4277 mg/g for Hg(II), and 4312 mg/g for Pb(II), while the fastest adsorption equilibrium can be reached within 3 minutes for Pb(II), achieving the highest Pb(II) adsorption rate of 8491.7 mg/(g.min) to the best of our knowledge till 2023. The sorption rate and partition coefficient of Hg(II) are 763.3 mg/(g.min) and 5040 mg/(g.μM), respectively. As a milestone in the historic development of advanced adsorbents based on organic polymers, this book comprehensively demonstrates new academic thought and concepts of molecular design, cleaner preparation, performance optimization, and vital application of macromolecular adsorbents. These materials have many amino, imino, sulfonic, and hydroxyl groups that can powerfully or reversibly adsorb heavy-metal ions over most nutritious metal

ions. This book is urgently required for researchers, developers, engineers, educationists, and managers in the field of environmental materials science and technology.

Graphical Abstract



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SECTION 1

INTRODUCTION AND RESEARCH BACKGROUND

CHAPTER 1

STRONG ADSORBENTS FOR HEAVY- AND NOBLE-METAL IONS

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Abstract: The development in synthesis and modification of polymer sorbents possessing powerful adsorbability towards heavy and noble metal