Applied Environmental Science and Engineering for a Sustainable Future

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Advanced Nano-Bio Technologies for Water and Soil Treatment

Springer

Applied Environmental Science and Engineering for a Sustainable Future

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Foreword

It is most fitting that this foreword is being written literally on the eve of the very first field-scale demonstration, two decades ago, of the efficacy of nanoscale zero-valent iron (nZVI) as a remediation technology for the treatment of contaminated groundwater at a manufacturing site in Trenton, New Jersey, USA. Memorialized in an *Environ. Sci. Technol.* journal article co-authored with Professor Wei-xian Zhang, the "Father" of the nZVI technology in 2001, this initial work was, in the clarity of retrospection, modest in scope and observations. We found that a kilo of nZVI slurry could be gravity-fed into the surficial sand-dominated aquifer impacted by trichloroethene, that nZVI aggregated very quickly, that the potential for subsurface travel seemed rather limited, and that multiple injections might be required to clean up a site, among others. What we could not have anticipated at that time was the spark this trailblazing work would eventually represent. Since those humble beginnings at Lehigh University, scores of research groups all over the world and some remediation practitioners are working with improved versions of the nZVI technology and a new generation of novel nanomaterials with a common goal—to identify, develop, and apply nanotechnology-based remediation agents to enhance environmental quality, especially that of soils and groundwater which can profoundly impact our potable water supplies. Among the most prolific contributors to this burgeoning community of nanoremediation researchers and practitioners are my colleagues from the Czech Republic who have edited this comprehensive and soon-to-be impactful tome.

The Editors, Principal Investigators, and Subject Matter Experts who contributed to *Advanced Nano-Bio Technologies for Water and Soil Treatment* are among the burgeoning field of applied environmental nanotechnology's most impactful contributors. Several of these scientists and engineers played key roles in the pivotal EU-led NanoRem consortium of 28 universities, national laboratories, and industry that, from 2013 to 2017, spearheaded the basic research, development, and application of a spectrum of promising nanomaterials for environmental remediation. Over the past 5 years, continued academic interest and, to some degree, the commercial development of key "nanoremediation" technologies are most encouraging. As is

demonstrated throughout the book, nanotechnology has the potential to enhance the performance and effectiveness of traditional remediation remedies by significantly accelerating the rate of contaminant transformation owing to smaller particle sizes. It can expand the spectrum of contaminant classes that can be treated as evidenced in the ability of catalyst-doped nZVI to degrade chlorinated benzenes, whereas iron powders and turnings are largely ineffective. Moreover, the diminution of particle size can enable improved and targeted delivery of remedial agents to subsurface contaminated areas that were previously difficult to reach or inaccessible. Nevertheless, against this largely optimistic backdrop, considerable work remains to fully characterize and appropriately vet the efficacy of these novel nanomaterials, assess the implications of their usage with respect to potential receptors, and conduct robust cost-benefit analyses as many of these technologies lack track records of performance in the field.

Naturally, the book begins with a part (Part I) on reductive technologies, showcasing the standard-bearer nZVI, which now has been showcased in more than 100 field-scale demonstrations around the world. It contrasts the many variations on nZVI with other reducing strategies (e.g., utilization of dithionate) and describes significant new enhancements associated with the application of DC electric fields to help drive nanoremediation agents through low-permeability subsurface formations such as clays. Part II introduces new nano-oxidation technologies, including high valence ferrates, which may provide exciting new water treatment applications. In Part III, the Editors focus on the integration of nanotechnology into the biotreatment of waters and groundwaters. The ex situ treatment of soils impacted by persistent organic pollutants such as polycyclic aromatic hydrocarbons using ligninolytic fungi and enzymes is addressed in Part IV. The Editors shift gears with Part V and focus on the implications of using nanoremediation—that is, they address the ecotoxicological impacts on receptors associated with the exposure to nanomaterials in the field. Part VI ties together the overarching observations and conclusions of the spectrum of nano- and nanobiotechnologies covered in the book and forecasts the future prospects of these technologies. Included is discussion on applications for emerging contaminants, new regulatory developments, and how these technologies might fit into new water security and quality strategies. I applaud the Editors, Chapter Authors, and Subject Matter Experts on their contributions and earnestly believe that this book will prove to be an invaluable reference for environmental remediation researchers and practitioners alike.

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Preface

One of the major issues that are currently dealt with all around the world is the depletion of clean/drinking water resources along with losing fertile soil, which would satisfy the burgeoning demand for food supply due to a growing population. Therefore, contamination from industry, environmental accidents, or improper wastewater treatment requires a fast, efficient, and cost-effective action to take. Advanced nanotechnologies, biotechnologies, or their combinations could represent a highly promising ecological and economical alternative to traditional remediation techniques. Due to the diverse character of the target pollutants, the key processes typically involve oxidation, reduction, sorption, and/or biological degradation. In this book, we aim to bridge theory and practice by sharing our experience with eliminating a wide range of pollutants from various resources utilizing innovative nanotechnologies, biotechnologies, and their possible combinations. What has not been omitted is evaluating the toxicity of both emerging pollutants and industrial nanoparticles. All the above-mentioned topics represent the core of an 8-year-long project aimed at applied research entitled "Environmentally friendly nanotechnologies and biotechnologies in water and soil treatment" (NanoBioWat) supported by the Technology Agency of the Czech Republic (project no. TE01020218). The following academic and industrial partners actively participated in the project as well as in the production of this book (all partners are based in the Czech Republic): Palacký University Olomouc, Regional Centre of Advanced Technologies and Materials; Technical University of Liberec, The Institute for Nanomaterials, Advanced Technology and Innovation; Institute of Microbiology of the Czech Academy of Sciences; AECOM CZ s.r.o.; AQUATEST a.s.; DEKONTA, a.s.; GEOtest, a.s.; LAC, s.r.o.; and MEGA, a.s. Leading researchers and experts from the particular fields, being either members of the above-mentioned consortium or based at other institutes, were asked to make their contributions to this book.

This book is organized into five topical parts and covers the most recent findings in the particular fields: (i) *Reductive technologies* for water treatment: this part deals with reductive remedial technologies applicable mainly to an in situ treatment of inorganic and organic contaminants. Nanoscale zero-valent iron is a major reagent

under study, yielding numerous results from various sites under various conditions. Other chemical reductants, such as dithionate, are discussed as well. The enhancement of either natural or chemical processes by DC electric field as a very promising method to accelerate and increase the efficiency of the remedial process along with reducing the cost is tackled as well. (ii) *Oxidative technologies* for water treatment: this part includes a basic overview of various innovative oxidation technologies applicable to water treatment with a strong focus on technologies based on iron compounds in high-valent states (co-called ferrates IV, V, and VI), including the properties of ferrates, their synthesis and applicability. Similarly, radical reactions and photooxidations are covered and discussed regarding their applicability to remediation techniques. (iii) *Biotechnologies for water treatment*: this part provides the overview of modern and advanced methods based on the application of microorganisms and their compartments, especially the combination of microbes or enzymes with nanotechnology applications. A special attention is also paid to recent findings concerning bioelectrical processes participating in the remediation processes. The presented results of nano-bio and bio-nano approaches demonstrate the feasibility and high efficiency of the combined methods. (iv) *Biotechnologies for soil treatment*: this part includes the overview of ex situ bioremediation treatment of contaminated soil. New details about mycoremediation technology using ligninolytic fungi for biodegradation of soil and groundwater contaminated with persistent organic pollutants (POPs) are discussed. The use of a composting technology for polycyclic aromatic hydrocarbons (PAHs) removal from contaminated soil is outlined with respect to its practical application. The last chapter of this part is dedicated to the techniques of bioremediation, including enzymes, biosurfactants, or genetically modified organisms use in real applications. (v) *Ecotoxicology* of both environmental pollutants and nanomaterials used for remediation: this part comprises theoretical support regarding novel findings on ecotoxicity of pollutants and nanomaterials. The importance of this part is underpinned by the fact that there is still lack of a suitable, comprehensive, and standardized set of tests for ecotoxicological evaluation of the novel nanomaterials; further research in this direction is needed.

Each part (i–iv) is organized as follows: it contains chapters focused on general description of the particular technologies followed by several field studies, 10 altogether, demonstrating the applicability of the particular technology. Moreover, the book has a concluding chapter dealing with **future prospects** for techniques treating contaminants of emerging concern in water and soils/sediments. Conclusions and suggestions made not only within this chapter but also throughout the whole book could be of interest to scientists and, primarily, practitioners who deal with water quality. Rising population is a phenomenon that entails different issues ranging from sustainable sources of clean water to cultivating soil for agricultural activities and feeding animals. The last part of the book contains a collection of five **technical chapters** (appendices) providing technical details on actions taken in relation with a pilot/full-scale application of key nano-/biotechnologies. Each chapter focuses on one specific aspect of the implementation of the selected technology/material such as nanoscale zero-valent iron injection into groundwater, field-scale contaminant

monitoring, and nanoparticle migration and transformation. Here we also cover protocols on (eco)toxicological assessment of nanoparticles and evaluation of changes in the microbial communities prior to and after nanoremediation.

Although other previously published papers and books (or book chapters) tackle certain aspects of advanced nano-/biotechnologies, this is the first time a complete and comprehensive treatise on the latest progress in innovative technologies has been published along with clear demonstration of the applicability of the particular methods on the basis of the results yielded in the pilot tests. Therefore, this multidisciplinary book will be suitable for broad readership including environmental scientists, practitioners, policymakers, and toxicologists and, of course, students of diverse fields involving material science, chemistry, biology, geology, hydrogeology, engineering, etc.

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