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Advanced Treatment Technologies for Urban Wastewater Reuse

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Volume 45

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- Aims and Scope
- Instructions for Authors
- Sample Contribution

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geoecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of

"pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Volume Preface

The ever-increasing shortage of water and the increasing needs for food security of the expanding world population and for irrigation water both in respect to good quality and quantity render the reuse a necessary condition. Currently, sustainable and safe urban water cycles have a high priority on the policy agenda of many countries around the world. Although reuse is accompanied by a number of benefits, several open questions still exist. For example, the applied treatments fail to completely remove biological and chemical microcontaminants, antibiotic-resistant bacteria, and resistance genes. The remaining organic matter in the wastewater after conventional treatment consists of a number of recalcitrant organic compounds including potential endocrine-disrupting compounds; many types of pharmaceutical compounds including antibiotics, disinfection by-products, personal care products, metabolites, and transformation products; and others. This leads to their subsequent release in the terrestrial and aquatic environment through disposal, storage, and reuse applications, which is of major environmental and health concern. Therefore, the identification of technologies that are able to remove such contaminants from wastewater, and the identification of means and solutions to overcome these problems and promote safe reuse practices, is of outmost importance.

Within the last decade much research has been performed in order to eliminate such contaminants present in low concentration (so-called micropollutants) from wastewater by appropriate treatment technologies. The newer ones are applied in addition to conventional treatment technologies. They are most often called "advanced treatment technologies". These mainly include a chemical step such as ozonation, hydrogen peroxide and light-driven technologies, and/or application of adsorption materials as well as filtration processes or combinations of these, in order to remove contaminants from the water. Within the last years there has also been intense research investigating the applicability of such advanced treatment technologies not just for the removal of organic microcontaminants but also for the removal of microorganisms, including bacteria, antibiotic-resistant bacteria, protozoa, and viruses.

Much published material is currently available. However, it is often scattered in different journals and books and is available only among various scientific communities. Therefore, it is timely to bring together this knowledge. In this book the potential and the limitations as well as the pitfalls and the knowledge gaps of the different advanced treatment technologies are presented. This volume offers a detailed overview on the capacity of currently applied and tested treatment technologies and on the integration of advanced processes to remove trace organic contaminants and microorganisms. This book is expected to draw the attention of experts; scientists; practitioners, from various fields of research, including analytical and environmental chemistry, toxicology, and environmental and sanitary engineering; and also treatment plant operators and policy makers.

The editors would like to acknowledge all the scientists involved in the development of the book and for creating the opportunity for fruitful discussions and exchange of ideas and knowledge and their patience with the editors. They would also like to thank warmly their co-workers of their research groups for their support in the daily working routine for giving them time to edit a book in such a vital field for the sustainable development of the urban environments and societies. Special thanks go to Dr. Lida Ioannou and Mr. Toumazis Toumazi (Nireas-International Water Research Center, University of Cyprus), Dr. Oliver Olsson (Institute of Sustainable and Environmental Chemistry, Leuphana University Lüneburg), and Ms. Xiaodi Duan (University of Cincinnati) for their significant contribution and administrative work and support during the development of the book.

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Contents

Scope of the Book *Advanced Treatment Technologies for Urban Wastewater Reuse*

Klaus Kümmerer, Dionysios D. Dionysiou, and Despo Fatta-Kassinos

Abstract This volume offers a comprehensive overview on the potential challenges and limitations of currently applied and tested treatment technologies, to remove trace organic contaminants.

Keywords Advanced treatment technologies, Antibiotic resistance, Biological and chemical treatment technologies, Contaminants of emerging concern, Wastewater treatment technologies

Urban wastewater treatment plants are regarded as the main sources for the spread of contaminants of emerging concern into the environment. The term refers to a diverse and expanding number of anthropogenic and natural compounds including

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industrial chemicals, compounds present in personal care products, pharmaceuticals, their metabolites, and transformation products formed during wastewater treatment. It is widely accepted that conventional activated sludge systems are inefficient in eliminating such contaminants, resulting thus in their dissemination into the environment. Advanced effluent treatment has also severe limitations depending on the type of treatment and compound to be removed. All of them can only remove certain compounds completely. Some compounds are removed only partially and others are not removed at all. In some cases, such as treatment with ozone or other oxidizing chemicals as well as effluent treatment and drinking water treatment with UV radiation, mostly unknown transformation products are formed which have been shown to be sometimes even more toxic than the parent compounds. The introduction of such compounds into the environment can potentially be even more pronounced when wastewater reuse schemes are implemented in water-scarce regions especially for agricultural and landscape irrigation. Furthermore, all advanced treatment comes along with elevated energy demand.

As a contribution to the knowledge in this field, this book focuses on the application of various technologies for the removal of contaminants of emerging concern, including not only organic chemicals but also antibiotic-resistant bacteria and other mobile resistance elements.

The second chapter presents four well-known and widely used technologies for the elimination of microcontaminants. Membranes, activated carbon, ozonation, and advanced oxidation processes are reviewed with regard to their efficiency in eliminating such contaminants from wastewater effluents. The analysis leads to the conclusion that the presented technologies can be useful for microcontaminant mitigation although none of them seems to be a universal barrier for them when used separately. Depending on the final use of the reclaimed water, the treatment may require the combination of several technologies that could lead to a substantial increase of the cost.

Activated sludge-based processes are environmentally friendly approaches to wastewater treatment. However, as mentioned already, conventional biological treatment alone may not be effective for all microcontaminants present in wastewater. The low removal efficiency of biologically persistent compounds and the presence of hydrophilic ones necessitate the integration of biological treatment with other membrane-based and physicochemical processes to ensure adequate removal at least of some of them. The third chapter provides a brief overview on the integration of advanced treatment processes including activated carbon adsorption, advanced oxidation processes, and high retention membranes with membrane bioreactors for the removal of microcontaminants.

Enhanced performance of biological processes for microcontaminant removal in wastewater treatment plants can be also achieved by adopting various general strategies based on different principles of operation including the increase of the biomass concentration, dynamic operating conditions able to modify the biocenosis composition and to induce alternative metabolic pathways required by xenobiotic biodegradation, and others. The fourth chapter tackles these issues and discusses technologies that involve the addition of adsorption or absorption media, advanced

oxidation processes like UV and UV/H_2O_2, and bioreactors operated with attached and granular biomass.

The detection of resistant microorganisms in the effluents of urban wastewater treatment plants disposed into surface water or reused for crop irrigation shows that conventional treatments and disinfection processes do not effectively control the spread of pathogens into the environment. There is a need for new and more effective disinfection processes and technologies. The aim of the fifth chapter is to briefly describe some of the emerging and antimicrobial-resistant microorganisms detected in wastewater, as well as the conventional and advanced available technologies for wastewater disinfection, and to evaluate and discuss their effect on these microorganisms. Moreover, regulations and policies on wastewater reuse are also discussed and compared.

The sixth chapter investigates the potential of different tertiary wastewater treatment technologies to minimize antibiotic-resistant bacteria and resistance genes in wastewater effluents, while the seventh chapter provides an overview on the microcontaminant behavior throughout conventional and advanced chemical and biological systems.

A very popular technology for the abatement of such contaminants, mainly on research level, is heterogeneous photocatalysis, which is often proposed to destroy micropollutants recalcitrant to biological treatment. However, the use of suspension of TiO_2 particles at an industrial scale is not easy. The eighth chapter reports on the evaluation of the efficiency of two photocatalysts immobilized on glass plates and cellulose fibers for the degradation of antibiotic compounds.

The development of integrated systems for wastewater treatment has been investigated in recent years not only for the improvement of control parameters but also to allow the routine reuse of wastewater to be effectively implemented. Chapter nine covers the evolution of the combined use of upflow anaerobic sludge blanket systems and constructed wetlands and also the integration of these technologies with advanced chemical processes.

The tenth chapter tackles the technological developments in treating wastewater by membrane bioreactors. In this chapter, various water reuse issues and standards applied in the USA are reviewed, and the challenges of membrane bioreactor systems and their status of applications are presented.

Reverse osmosis is considered today as a reliable and essential water reclamation technology for producing high-quality water for reuse. The concentrate, which is a waste stream produced from the process, is volumetrically substantial and contains environmentally harmful compounds and therefore can cause severe environmental impacts if disposed of into the environment. The eleventh chapter presents an overview of the concentrate quality and various technologies for treating it. The technologies discussed include mineral recovery, electrochemical desalting, and treatment through adsorption, coagulation, and oxidative degradation. Other alternative strategies including emerging technologies for increasing water recovery rate from water reclamation plant are also discussed.

Potable water reuse through the use of treated wastewater effluents has been practiced for more than 50 years. The majority of projects worldwide are

characterized as indirect potable water reuse, where an environmental buffer like groundwater aquifer or a surface water reservoir provides retention, additional attenuation, and blending prior to use as drinking water. Due to the recognition of contaminants of emerging concern occurring in reclaimed water that might exhibit adverse health effects, additional advanced treatment processes have been implemented. With increasing reliability of advanced water treatment processes and operational experience over several decades, the role of the environmental buffer to provide treatment and retention time has been revisited in projects that came online during the last 10 years. Recent trends in direct potable water reuse are presented and discussed in the penultimate chapter.

The book closes with an outlook that provides the reader with information on the potential strategies that could be applied in order to tackle the problems related with the presence of contaminants of emerging concern and wastewater.

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