Green Energy and Technology

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Advanced Wastewater Treatment Technologies for the Removal of Pharmaceutically Active Compounds

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Green Energy and Technology

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Darkness cannot drive out darkness, only light can do that. Hate cannot drive out hate, only love can do that.

Martin Luther King

Preface

Water pollution is one of the most serious environmental threats of the twenty-first century, creating much disturbance to the benign nature of the environment. The toxic effects of this phenomenon on aquatic life and its deleterious impacts on maintaining the balance of the ecosystem have been widely investigated in recent years, as reported by scientists around the world. The scarcity of clean water resources is therefore an outcome of this global issue, leading to severe health, economic, and social concerns. The detection and remediation of contaminants of emerging concern (CECs) in water bodies in particular have added further challenges to the scientific community worldwide. These issues have created innumerable risks to humans and the environment; such aspects have not yet been deeply investigated and fully understood. To solve these issues, enormous efforts have been initiated by the scientific community to explore and develop efficient and economic methods to remove such compounds from polluted waters.

The present book covers an overview of the fundamental aspects related to the detection, quantification, and removal of pharmaceutically active compounds (PhACs) as an important class of contaminants of emerging concern. Critical discussions are provided regarding the fate of PhACs using a variety of treatment systems and technologies as well as the mechanisms involved in their removal using a wide range of biological and physico-chemical methods. The book is aimed at discussing the sustainability aspects of various methods developed and used in the elimination of PhACs in efforts to help decision-makers select the best available technique among the existing alternatives.

The fundamentals presented in various chapters of this book will aid readers and researchers in designing innovative future studies to address the remaining gaps in the literature for further developing sustainable wastewater treatment technologies to deal with toxic PhACs. To achieve these goals, the latest achievements of the scientific community are carefully retrieved, analyzed, and critically discussed from the most reputable platform of ever-increasing science, Web of Science (WoS; previously known as Web of Knowledge), for critical analysis and discussion. Furthermore, many complementary references are included in each chapter of the book to help

readers and researchers search for more detailed information regarding the fundamentals and applicability of the technologies discussed in this book. We sincerely hope that this book will benefit a wide range of academicians, researchers, industrialists, and policy-makers, seeking further development and implementation of sustainable wastewater treatment technologies to remove pharmaceutically active compounds as well as other types of contaminants of emerging concern.

Sint-Katelijne-Waver, Belgium Mohammadreza Kamali

About This Book

This book provides an overview of the most important biological and physico-chemical (waste)water treatment technologies developed from time to time in the literature in efforts to remove pharmaceutically active compounds (PhACs). Chapter 1 of the book summarizes and discusses the available literature on the occurrence, environmental concentrations, fate, possible effects of the typical PhACs after these are introduced into the receiving environments. Chapter 2 introduces the advanced techniques for the detection of various PhACs, their quantification, and methods employed to identify the mechanisms involved in removing the PhACs using various physico-chemical and biological treatment approaches. Chapter 3 covers a discussion on the scientometric analysis for the identification, retrieval, and analysis of the scientific documents published from the Web of Science (WoS) on the application of various biological and physico-chemical treatments to deal with the PhACs. Chapters 4–7 of the book address the critical discussion of the applicability of the most popular biological wastewater treatment technologies, including activated sludge, anaerobic digestion, microbial fuel cells, and constructed wetlands, to remove various types of PhACs from water streams. The mechanisms involved in the removal of PhACs using these technologies and possible interactions between such compounds and the microbial communities are elegantly discussed. The mechanisms involved in the application of membrane separation and adsorption technologies and their applications for the removal of PhACs are critically evaluated with the relevant examples in Chaps. 8 and 9 of the book. The last two chapters (i.e., 10 and 11) are aimed at discussing the potential of homogeneous (Chap. 10) and heterogeneous (Chap. 11) advanced oxidation processes (AOPs) used in the elimination of PhACs. These two chapters deeply discuss the mechanisms involved in the removal of various types of PhACs along with the pros and cons involved in the application of both energy-free and energy-intensive AOPs. Overall, the entire book outlines the existing research gaps involved in the development of sustainable technologies for the removal of pharmaceutically active compounds and provides valuable recommendations for further future studies.

Contents

Abbreviations

3DPT	Three-dimensional printing technology
AC	Activated carbon
ACI	Average citation per item
ACMFCs	Air cathode microbial fuel cells
AD	Anaerobic digestion
AERs	Anion-exchange resins
AnMBRs	Anaerobic membrane bioreactors
AOPs	Advanced oxidation processes
AOXs	Halogenated organic compounds
ARBs	Antibiotic-resistant bacteria
ARGs	Antibiotic resistance genes
AS	Activated sludge
Ass	Active species
ATP	Adenosine triphosphate
BC	Biochar
BDD	Boron-doped diamond
BET	Brunauer–Emmett–Teller (theory)
BOD	Biological oxygen demand
CB	Conduction band
CD	Corona discharge
cDNA	Complementary DNA
CECs	Contaminants of emerging concern
CFs	Carbon fibers
CMC	Critical micelle concentration
CMs	Conductive materials
CNTs	Carbon nanotubes
COD	Chemical oxygen demand
CW	Constructed wetlands
DBD	Dielectric barrier discharge
DHA	Dehydrogenase activity
DHEA	Dehydroepiandrosterone

DIET	Direct electron transfer
DO	Dissolved oxygen
EC	Electrical conductivity
EET	Extracellular electron transfer
EMEA	European Medicine Agency
EO-AOPs	Electrochemical advanced oxidation processes
EPR	Electron paramagnetic resonance
EPSs	Extracellular polymeric substances
ESI	Electrospray ionization
ESR	Electron spin resonance
FO	Forward osmosis
FTIR	Fourier transform infrared spectroscopy
FWS-CWs	Water surface flow constructed wetlands
GA	Gamma irradiation
GAC	Granular activated carbon
GADP	Gliding arc discharge
GC	Gas chromatography
GC–MS	Gas chromatography with mass spectrometry
GC–MS/MS	Gas chromatography with tandem mass spectrometry
GDP	Glow discharge plasma
GO	Graphene oxide
HDL	High-density lipoprotein
HE-AOPs	Heterogeneous advanced oxidation processes
HLR	Hydraulic loading rate
HO-AOPs	Homogeneous advanced oxidation processes
HPLC	High-performance liquid chromatography
HRs	Hydroxyl radicals
HRT	Hydraulic retention time
HSF-CWs	Horizontal subsurface flow constructed wetlands
IF	Infrared
LC	Liquid chromatography
LC–MS	Liquid chromatography with mass spectrometry
LC–MS/MS	Liquid chromatography with tandem mass spectrometry
LECA	Light expanded clay aggregates
LOEC	Lowest observed effect concentration
LTQ	Linear trap quadrupole
MAs	Metal-based adsorbents
MBBRs	Moving-bed biofilm reactors
MBRs	Membrane bioreactors
MEUF	Micellar-enhanced ultrafiltration
MFC	Microbial fuel cells
MGEs	Mobile genetic elements
MOFs	Metal-organic frameworks
MOx	Metal oxides
MS	Mass spectrometry

MUVP	Microwave-UV plasma
NAC	NH_4Cl-triggered activation
NF	Nanofiltration
NGS	Next-generation sequencing
OC	Oseltamivir carboxylate
OLR	Organic loading rate
ORR	Oxygen reduction reaction
ORs	Oxidative radicals
OUR	Oxygen uptake rate
PC	Photocatalysis
PCOz	Photocatalytic ozonation
PCR	Polymerase chain reaction
PEC	Photoelectrocatalytic
PEM	Proton-exchange membrane
PhACs	Pharmaceutically active compounds
PI	Periodate
PL	Photolysis
PMS	Peroxymonosulfate
PPCPs	Pharmaceutical and personal care products
PS	Persulfate
QIA	Quantitative image analysis
qPCR	Quantitative PCR
Q-TOF-MS	Quadrupole time-of-flight mass spectrometry
rGO	Reduced graphene oxide
RO	Reverse osmosis
ROS	Reactive oxygen species
SDGs	Sustainable Development Goals
SEM	Scanning electron microscopy
SPE	Solid-phase extraction
SRT	Solid retention time
SSA	Specific surface area
STAs	Spin-trapping agents
TEM	Transmission electron microscopy
TFC	Turbulent flow chromatography
TFCMs	Thin-film composite membranes
TMCs	Transition metal carbides
TOC	Total organic carbon
TSS	Total suspended solids
VB	Valence band
VFAs	Volatile fatty acids
VSF-CWs	Vertical subsurface flow constructed wetlands
WoS	Web of Science
WWTPs	Wastewater treatment plants
XPS	X-ray photoelectron spectroscopy

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