Activated Carbon

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Solutions for Improving Water Quality

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Activated Carbon: Solutions for Improving Water Quality

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AWWA Sr. Manager of Editorial Development and Production: Gay Porter De Nileon
AWWA Sr. Technical Editor/Project Manager: Martha Ripley Gray
Cover Art: Cheryl Armstrong, AWWA Sr. Production Editor
Production: Cheryl Armstrong; Sheryl Tongue, Stonehill Graphics

Library of Congress Cataloging-in-Publication Data
Chowdhury, Zaid K.
Activated carbon : solutions for improving water quality / Zaid K. Chowdhury, R. Scott Summers, Garret P. Westerhoff, Brian J. Leto, Kirk O. Nowack, Christopher J. Corwin ; Laurel B. Passantino, technical editor.
pages cm
Includes bibliographical references and index.
ISBN 978-1-58321-907-2 (hardback) -- ISBN 1-58321-907-2 (hardback) -- ISBN 978-1-61300-202-5 (electronic) -- ISBN 1-61300-202-5 (electronic) 1. Water--Purification--Adsorption. 2. Water--Purification--Organic compounds removal. 3. Carbon, Activated. 4. Water quality. I. Title.
TD449.5.C46 2012
628.1'66--dc23
2012039033

Printed in the United States of America

ISBN-13, print: 978-1-58321-907-2
ISBN-13, electronic: 978-1-61300-202-5
ISBN-10, print: 1-58321-907-2
ISBN-10, electronic: 1-61300-202-5

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Contents

List of Figures

List of Tables

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As the Director of Applied Research for the Water Division of ARCADIS, Zaid K. Chowdhury serves as the top water treatment expert for the firm and is responsible for resolving challenging technical issues in the area of water treatment. His long tenure with the firm and active involvement in the professional and research circles has earned him a considerable reputation in the industry as an expert in various water treatment technologies including GAC. His direct involvement in the selection of GAC technologies for water treatment plants and in the evaluation and design of GAC facilities at many major water plants, including those for the cities of Scottsdale and Phoenix in Arizona, have helped him develop a keen understanding of GAC applications for adsorption and biological treatment media.

In addition, Chowdhury has been involved in numerous water treatment–related studies and research projects as well as in projects that augmented the knowledge base on treatment technologies relevant to various water quality regulations, including the Disinfectants and Disinfection By-Products Rule, the Long-Term 2 Enhanced Surface Water Treatment Rule, and the Arsenic Rule.

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R. Scott Summers, PhD

Since 1998, Dr. Summers has been a professor of environmental engineering at the University of Colorado. He spent two years as a research associate at the German Water Works Research Institute (DVGW) at the University of Karlsruhe, 10 years as a professor at the University of Cincinnati, and was a Fulbright Professor at the University of Crete (Greece). He has been the Principal Investigator or co-PI of more than 30 research projects, 20 of which have focused on activated carbon. He has served as the research advisor for 25 PhD and 50 MS students and has coauthored more than 250 publications and 150 presentations.

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Former chair and chief executive officer of Malcolm Pirnie and longtime director of Malcolm Pirnie's drinking water programs, Garret P. Westerhoff is a leading national expert with more than 40 years' experience on water treatment systems, water resources planning, and design and management of water systems. He has pioneered the applications of innovative technologies such as high-rate and direct filtration and led design of the nation's first major installation of granular activated carbon (GAC) treatment to remove organics from drinking water for Cincinnati, Ohio.

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Brian Leto is a senior process design engineer in Malcolm Pirnie/ARCADIS. Leto has contributed to design and construction of activated carbon applications including gravity applications of post-filter GAC contactors and filter adsorbers, pressure applications of GAC adsorption, and powdered activated carbon (PAC) storage and feed systems. He has conducted pilot studies of variations of activated carbon filtration including biologically active filters and adsorption and operated liquid and vapor phase activated carbon systems; trained operations staff regarding the operation of activated carbon processes; and optimized activated carbon operations after construction. In addition to his activated carbon experience, Leto has contributed to planning, design, and construction of multiple drinking water treatment and wastewater treatment and reuse projects during his 14-year career with Malcolm Pirnie/ARCADIS, including conventional and reverse osmosis water treatment plants and Class A+ wastewater reuse facilities.

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Kirk Nowack is a senior process engineer with Malcolm Pirnie, the Water Division of ARCADIS. He currently leads a national team within Malcolm Pirnie that provides technical guidance and support for projects involving activated carbon. Nowack has extensive experience in all facets of planning, designing, and optimizing activated carbon treatment systems. He has also conducted research in the areas of activated carbon production and adsorption performance, and his findings have been published in *Carbon*, *Environmental Science and Technology*, and the *Journal American Water Works Association*. He led the development of a thermal technique that greatly enhances the adsorption capacity of commercially available activated carbons, and this technique has since been patented. Nowack previously worked as a water quality manager for the Pennsylvania-American Water Company, where he also served as a licensed water treatment plant operator. He is a member of the American Water Works Association and holds a PhD in environmental engineering from the Pennsylvania State University.

Christopher J. Corwin, PhD, PE

Chris Corwin earned his PhD from the University of Colorado at Boulder, where he investigated the removal of trace organic compounds from drinking waters with granular activated carbon. His research on activated carbon has been published in *Environmental Science & Technology*, *Water Research*, and the *Journal American Water Works Association*. During his graduate studies, Corwin participated in more than 25 bench-scale activated carbon evaluations for utilities across the country. These included the evaluation of PAC and GAC for the control of organic matter, disinfection by-product formation, taste-and-odor compounds, specific organic contaminants, and micropollutants. In the eight years prior to pursuing his advanced degrees, he acquired a diverse portfolio of experience in civil and environmental design.

Corwin is a licensed Professional Engineer in the state of Colorado and is a member of the American Water Works Association. He holds a BS in civil engineering from the University of Kentucky and MS and PhD degrees in civil engineering from the University of Colorado.

Laurel B. Passantino, PE (Technical Editor)

While working on this book, Laurel Passantino was a senior project engineer in the Drinking Water Process and Planning Engineering Group of Malcolm Pirnie/ARCADIS. She has authored or been a contributing author to over 30 publications and presentations in the area of water quality and treatment. Passantino has been involved in all aspects of drinking water treatment projects, including treatment process evaluations, water quality master planning, infrastructure master planning, regulatory compliance, and pilot studies. In particular, she has experience in coagulation and filtration, high-rate clarification, disinfection by-product formation and control, granular media filtration, granular activated carbon adsorption, arsenic treatment, and ultraviolet disinfection. Her activated carbon experience includes master planning for several communities in the Phoenix area as well as preliminary design for the second largest post-filter granular activated carbon facility in the United States, which is located in Scottsdale, Arizona.

continued next page

Passantino is a licensed Professional Engineer in the states of Arizona and Pennsylvania and is a member of the American Water Works Association. She holds a BS in civil engineering from Duke University and a MS in civil and environmental engineering from the University of New Hampshire.

Acknowledgments

As the book's coauthors, we assume responsibility for the research, writing, coordinating, and reviewing the entire contents of the book. Throughout the process, we had the assistance of our technical editor, Laurel Passantino, to keep us on track and to bring the prose of a diverse group of authors into an integrated text. We would also like to thank Jessica Cunningham, Kelley Newman, Alex Rivas, Andrea Odegard-Begay, Steve Porteous, and Andrea Traviglia for their contributions to the manuscript; and Amit Chattopadhyay, Jim Dettmer, Richard Pohlman, and Peter Tymkiw for providing peer review of early drafts.

We also recognize the many utility leaders who participated in an opinion survey conducted in December 2001 and January 2002 for Malcolm Pirnie Inc. by the BTI Consulting Group (Boston), others who offered advice and suggestions during interviews, and those who contributed material for the case studies that serve as the foundation for much of the book.

Special thanks go to Richard Brady, PE, BCEE, Richard Brady & Associates, and Robert M. Clark, PhD, US Environmental Protection Agency (retired), for reviewing the entire manuscript.

Finally, we thank our advocates and supporters at the American Water Works Association. Special thanks to Gay Porter De Nileon, Martha Ripley Gray, Cheryl Armstrong, Daniel Feldman, and Sheryl Tongue at Stonehill Graphics.

Without the help of these individuals, this book would not have been published, and we are grateful to all of them. Though bringing this project to completion required the help of many, we reserve for ourselves responsibility for any shortcomings the book may have. It is our hope that *Activated Carbon: Solutions for Improving Water Quality* will help its readers meet the challenges they face in bringing high-quality drinking water to their consumers at reasonable costs of service.

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Preface

Determining the appropriate treatment regime to provide safe drinking water for customers continues to challenge drinking water purveyors. Source water quality is becoming more compromised as global demand increases, high-quality sources are depleted, and improvements in analytical methods reveal increasingly lower concentrations of contaminants in treated water. Regulatory agencies struggle with adequate resources to make sound scientific judgments regarding safe levels of contaminants in drinking water while media reports of detected levels of chemicals and microbes leave customers apprehensive about the safety of what comes out of their faucets every day.

Maintaining microbiological quality continues to be a cornerstone of water treatment as reinforced by the unfortunate incidence of waterborne disease in impoverished and developing nations. Nevertheless, conventional disinfectants used effectively in treatment for more than a century produce by-products that may have long-term chronic health effects, and sources degraded by anthropogenic inputs increase the portfolio of chemical contaminants that must be addressed. Personal care products and pharmaceuticals in drinking water are reported with increasing frequency in the global media, while the effects on humans remain unresolved.

Through all of this uncertainty, proactive measures that can reduce a wide variety of contaminants to low concentrations through multi-objective treatment remain an important element of robust and reliable drinking water production. Activated carbon, one of the oldest treatment technologies, is once again demonstrating its value in these challenging times. Activated carbon is simple to operate as an adsorption medium, serves as a proactive barrier for contamination, and does not produce by-products from its use. It can be reactivated and reused. And it removes compounds that customers can perceive with their senses—taste-and-odor compounds—as well as reduces a suite of potentially harmful chemical contaminants to low concentrations.

Many books have been written about granular activated carbon. Some focus on the theory of performance and removal mechanisms while others focus on design features. This book focuses on solutions. It describes the challenges facing water providers to provide safe water that is acceptable to their customers, utility experiences using activated carbon, activated carbon applications, and design and procurement approaches. The appendices include detailed case studies and a life-cycle assessment demonstrating favorable sustainability considerations for activated carbon when compared to other treatment technologies.

Never before has all of this information been together in one location. The what, why, and how of activated carbon are connected in this book and demonstrate why this treatment technology has maintained its status as an integral treatment technology in the quest for pure water over millennia.

Enjoy the story!

Introduction

Water purveyors throughout the globe have been, and continue to be, challenged to support existing and growing populations with an adequate and safe water supply. Historically, communities developed where water supplies were available and abundant. For example, the settlements resulting from the westward migration in the United States in the 1800s were often determined according to where water supplies were found. Now, however, there are few new locations where safe water supplies are available and abundant, either in the United States or globally. Instead, the challenge of maintaining and protecting drinking water supplies from further degradation is high on the minds of water purveyors and environmentally minded individuals and groups. Existing supplies continue to be threatened by microbiological and chemical contaminants introduced by increasing populations and associated economic development as well as by natural sources of contamination.

Water scarcity is a constant area of concern in major metropolitan areas in arid regions, and climate change is affecting how regions that previously had sufficient resources view their supplies into the future. These scarcity issues are driving water purveyors to use lower-quality water sources to meet increasing demand. At the same time, improved analytical techniques are able to detect compounds at lower and lower concentrations, either revealing contaminants that previously had not been detected or indicating the presence of contaminants that have been recently introduced into the water supply. Although health effects of many of these micropollutants are not currently known and may not be known for decades or longer, consumers are rightfully concerned about their presence in drinking water, and water purveyors must respond.

In the fundamental charge to protect public health, water purveyors rely on a combination of treatment and watershed protection to meet water quality goals and regulations. In meeting these goals, water purveyors should consider both the quantity and quality of the supply and choose suitable treatment approaches. The approaches are often a combination of physical, chemical, adsorption, and biological processes. The challenge is to determine the best combination of processes that protect public health and meet customer desires and regulatory requirements for water quality while doing so in a financially responsible manner.

The Case for Activated Carbon

Activated carbon is an adsorption medium and its use is considered an advanced technique for meeting many water quality demands. Treatment with activated carbon is not new and has in fact been used for thousands of years to improve the quality of drinking water. It has been used in various forms (powdered and granular) around the globe in a multi-objective manner, removing heterogeneous compounds that produce color and are precursors to contaminants upon disinfection, trace organic and inorganic contaminants, and taste-and-odor compounds. Activated carbon also has the flexibility to be operated in both adsorption and biological modes. In the latter, it provides a large surface area for organisms to populate and biologically degrade contaminants. Utilities may implement activated carbon for several reasons, including regulatory compliance, positioning for future regulations, public health protection and customer confidence, and sustainability considerations.

Compliance With Existing Regulations

For most water systems, the biggest driver for implementing activated carbon treatment is to gain compliance with water quality regulations. The US Congress originally passed the Safe Drinking Water Act (SDWA) in 1974 to protect public health by regulating the nation's public drinking water supplies. The law was subsequently amended in 1986 and 1996. The two categories of drinking water standards in the SDWA are:

1. *Primary Standards:* Legally enforceable standards that limit the levels of specific hazardous contaminants having an adverse effect on human health.
2. *Secondary Standards:* Nonenforceable guidelines for nonhazardous contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. USEPA recommends secondary standards to water systems but does not require systems to comply unless the state chooses to require compliance.

Several individual regulations fall under the umbrella of the SDWA. The following components are most likely to influence a water purveyor's decision to implement activated carbon.

Disinfectants and Disinfection By-products (D/DBP) Rule

For more than 100 years, the practice of disinfecting drinking water using chlorine and its compounds has protected consumers from waterborne diseases by inactivating pathogens. However, disinfectants react with organic matter in the water supply, and many of the by-products formed are of concern to public health. The primary objective of the D/DBP Rule, which was promulgated in two stages, is to reduce exposure of drinking water consumers to DBPs such as total trihalomethanes (TTHMs), the sum of five haloacetic acids (HAA5), bromate, and chlorite while still providing adequate disinfection. The rule also contains requirements for removing DBP precursors, as demonstrated by total organic carbon (TOC) removal using a treatment technique termed *enhanced coagulation*, which means achieving additional TOC removal by adding increased amounts of coagulant over what is required for turbidity removal.

To adequately protect public health from many waterborne diseases, the practice of disinfection must be continued. Activated carbon helps water purveyors comply with the D/DBP Rule by providing an additional removal mechanism for TOC. Because TOC is a major contributor to TTHM and HAA formation upon chlorination, reducing the TOC will also reduce the formation potential of these DBPs.

Enhanced Surface Water Treatment Rule

The Enhanced Surface Water Treatment Rule (ESWTR) also has two stages, corresponding to the two stages of the D/DBP Rule. The objective of the ESWTR is to confirm that disinfection is not compromised by utilities in their effort to minimize DBP formation. Compliance is demonstrated by providing treatment processes that remove or inactivate microorganisms. The final stage of this rule, the Long-Term 2 Enhanced Surface Water Treatment Rule, requires additional removal or inactivation of *Cryptosporidium*, depending on the source water quality. The USEPA's treatment toolbox for *Cryptosporidium* grants 0.5 log removal when granular activated carbon (GAC) filters or contactors are placed in series with another filtration process (granular media or membrane).

Unregulated Contaminant Monitoring Rule (UCMR) and Contaminant Candidate List (CCL)

The CCL is used by USEPA to identify contaminants that may be regulated in future, and the UCMR is used to gather data on the occurrence of unregulated contaminants in drinking water systems. Although there are no enforceable standards for UCMR contaminants, data are collected and reported to USEPA to assist with future regulatory policymaking. The first CCL was published in March 1998 and contained 60 contaminants under regulatory consideration. Based on the data from the first monitoring cycle of the UCMR, USEPA published the second drinking water CCL (CCL2) in 2005. The list carried forward 51 of the original 60 contaminants, and 9 were removed because sufficient data were collected and indicated that further regulating action was not required. In addition to the CCL2 list, the USEPA published the UCMR2, which required monitoring of 26 contaminants.

The third CCL (CCL3) was published as a draft in February 2008 and was finalized in 2009. After evaluating approximately 7,500 potential contaminants based on occurrence, production, and toxicology, an expert panel under the direction of the National Research Council (NRC), National Drinking Water Advisory Council (NDWAC), and Science Advisory Board (SAB) helped USEPA systematically narrow down the list of potential contaminants in the CCL3 to 104 chemicals and 12 microbiological contaminants. UCMR3 was proposed in February 2011. When it is finalized, this rule will require monitoring of 30 contaminants during the 2013–2015 time frame.

Many of the contaminants on the CCL and monitored in the UCMR can be effectively removed using activated carbon. Consequently, should any of them be regulated either individually or as a class of contaminants in the future, activated carbon will become an important part of the process train for many utilities.

Positioning for Future Regulations

The continued pressure to improve water quality is mounting as source waters are challenged with a variety of micropollutants. These contaminants include those being detected because of improved analytical methods and those being introduced into source waters at higher concentrations, such as personal care products and pharmaceutically active compounds. Although effective for reducing concentrations of these micropollutants, chemical oxidation does not convert them into carbon dioxide and water, and it is often unknown what compounds form in their place. Therefore, true removal processes are being revisited with renewed vigor. Membrane processes are improving, but only higher-pressure options such as nanofiltration and reverse osmosis can address most of these micropollutants. The following emerging issues are likely to affect utility strategies for using activated carbon in their treatment systems.

MTBE and Perchlorate

Both MTBE (methyl-*tert*-butyl-ether) and perchlorate continue to gain public interest and deserve more scrutiny. As two of the original contaminants on the CCL in March 1998, MTBE and perchlorate have undergone UCMR monitoring to determine the viability of regulating the chemicals or removing them from the list.

In UCMR monitoring of more than 3,400 systems, MTBE was detected in only 0.5 percent of the systems, and perchlorate was detected in nearly 4.5 percent of samples. It is still unclear whether the MTBE concern is in localized regions or widespread throughout the country. It is very likely that if MTBE detections are localized, the monitoring would spark state regulation rather than federal. While the USEPA is still in the process of revising its MTBE risk assessment, California has set an enforceable standard of 14 μg/L for MTBE. Because perchlorate is more widespread, it is more likely to warrant federal regulation.

Endocrine Disrupting Compounds (EDCs) and Pharmaceuticals

Pharmaceuticals, personal care products, and some household compounds are starting to appear in drinking water systems around the United States and in Europe. Some of these compounds are known to be endocrine disrupting compounds (EDCs), but their significance in drinking water is still not clear. Future monitoring and testing are needed to determine which of these compounds, if any, pose a threat to human health and at what dose. At that point, monitoring water systems for such compounds and evaluating ways to remove the compounds from the water may be necessary.

Nitrogenous Disinfection By-Products

The potential exists for future regulation of nitrogenous disinfection by-products (N-DBPs). Many N-DBPs can be found in treated drinking water; however, the most common ones include the various species of nitrosamines, particularly *N*-nitrosodimethylamine (i.e., NDMA) and halonitromethanes. Six of the nine possible nitrosamines are currently included in the CCL3 list. Based on the results of UCMR2 monitoring, NDMA is the most commonly occurring nitrosamine in drinking water. Because of the significant occurrence and the associated high carcinogenic potency of NDMA, it is anticipated that USEPA will consider developing a regulation for NDMA in the near future.

Carcinogenic Volatile Organic Compounds (cVOCs)

Under the auspices of six-year review, USEPA is currently reviewing the standards for trichloroethylene (TCE) and perchlorethylene (PCE). With USEPA's strategic direction to regulate contaminants by groups, USEPA is considering the revised TCE/PCE standards in a combined regulation for carcinogenic VOCs. Eight different cVOCs are currently regulated, and USEPA is considering regulating up to eight more in the group of cVOCs. A group regulation for cVOCs is expected to be proposed in 2013. Although the regulatory limits for specific VOCs are not known at the time of preparing this book, it is widely anticipated that the current regulatory limits for TCE and PCE will be lowered from the current limits of 5 μg/L. The existing limits were based on the limits of the analytical techniques available at the time; however, because analytical methods have been refined, lower detection limits are feasible compared to when the first VOC regulations were developed.

Activated carbon is the most widely accepted technology used to adsorb many of the organic compounds of concern. Many water utilities around the world are currently using activated carbon for removal of Natural Organic Matter (NOM), Synthetic Organic Chemicals (SOCs), and taste-and-odor compounds. It also helps with N-DBPs because systems that lower their TTHM and HAA formation potential are less likely to use chloramine, thereby avoiding formation of N-DBPs.

Public Health Protection and Customer Confidence

The state and federal drinking water regulations that provide legally enforceable standards are the foundation for a water utility's public health commitment to its customers and the public. However, meeting the standards does not result in zero risk; rather, the standards are based on peer-reviewed science, including data on how often the regulated contaminant occurs in the environment, how humans are exposed to it, the health effects of exposure, and cost considerations. A water system can elect to provide treatment to a quality higher than that required by a standard. However, most systems find it difficult to obtain the financial resources that may be needed to provide treatment levels above those required to comply with state and federal standards.

Science is continually identifying the presence of additional chemicals in the drinking water supply, often in minute concentrations. While evidence is lacking that many of these pose a significant threat to public health, customers may become concerned at the presence of these compounds in their water supply, especially when reported by various media outlets. Because we are in an era of information overload, multitasking, and sound bites, few people have the time, desire, or even sufficient technical expertise to fully examine and form their own educated opinion on all of the issues and challenges facing them today. Hence, opinions are often based on perceptions formed by instincts and input received from a variety of sources.

Much of the media only focus on water issues during droughts, floods, proposed rate increases, reported failure, inefficiencies, or health emergencies. Seldom is there a positive story of how well a water utility is performing, the quality of life it supports, or the health protection it is providing. With most of the media information reporting the negative, it is understandable that many customers are biased with negative perceptions and concerns about the quality of their water.

To counter these negative perceptions, it is critical for utilities to provide their customers with outstanding customer service and to become trusted partners in the goal to protect public health. During a Gallup Organization's Drinking Water Customer Satisfaction Survey for the USEPA of 1,000 households nationwide in 2002, general drinking water consumer knowledge and public confidence with information sources were assessed. Findings from the survey demonstrated that Americans recognize the importance of receiving information on aspects of their drinking water and value being informed. This accentuates the need for honest, unbiased information reaching the customer. Another way for utilities to demonstrate their commitment to understanding customer concerns is to provide additional treatment barriers for unregulated contaminants such as micropollutants, taste- and odor-causing (T&O) compounds, or aesthetic issues. However, the decision to implement additional treatment must be sensitive to the ability of the community to afford the increased level of treatment.

The bottom line is that while most of our water treatment systems do a good job with the technologies they have in place, a broad spectrum of chemicals in a water supply remain that are not being removed or reduced to the degree they could be by using activated carbon technologies. Although implementation of GAC treatment technologies costs money and will result in increased water rates, implementation needs to be considered in the light of improved public health protection. The current economic conditions may inhibit the ability to incur these costs; however, the value should be considered in strategic long-range planning.

Sustainability Considerations

It is sometimes thought that the use of a GAC treatment technology would result in a significant environmental burden. This needs to be considered in light of other options that could be used to achieve a desired treatment effect. In an effort to reduce the environmental burdens associated with producing drinking water, many water utilities have begun evaluating the sustainability of potential treatment scenarios prior to implementation. As a water utility evaluates the potential use of various processes to reduce disinfection by-products, one approach to assessing sustainability is a life-cycle assessment (LCA). LCA, which is often referred to as *cradle-to-grave*, is a systematic approach that follows the International Organization of Standardization (ISO) 14040 standard to quantify potential environmental burdens of a product or process over its lifetime.

Appendix A contains an example illustrating the use of LCA to evaluate the environmental impacts of typical processes to reduce DBPs. Three treatment technology scenarios were evaluated in the example: (1) GAC filter adsorbers, (2) GAC post-filter contactors, and (3) enhanced coagulation followed by disinfection using chloramines. In the appendix A example, no single scenario had significantly lower results across all LCA categories and sustainability measures analyzed, challenging the thought that GAC results in a significant environmental burden.

Concerns With Activated Carbon

Despite its merits, activated carbon has yet to be accepted as a "baseline" process in water treatment. Nevertheless, the USEPA recognized the significant benefits of activated carbon in its seminal 1986 Amendments to the Safe Drinking Water Act and chose GAC as a best available technology (BAT) for treating a suite of chemical contaminants. Since that time, some water purveyors have chosen to implement GAC as a treatment technique, while others have found different and often less expensive ways to meet federal and state water quality requirements. The use of GAC treatment is expensive, both in initial capital cost as well as in on going operational costs associated with reactivating and replacing the media. The information in this book describes methods and techniques to minimize these costs. The cost of GAC treatment should be considered in light of the benefits accrued by significant removal of a broad spectrum of organic contaminants from a water supply and the ability to furnish customers with a water quality that not only meets current regulations but also reduces risks that may result from currently unregulated contaminants and the risks of unintended consequences that may be associated with other treatment methods. The end result is the ability to furnish customers with a very high-quality water that is likely to improve their quality of life and protect human health.

Book Organization

Many books and book chapters have been written on activated carbon treatment. Most focus on removal mechanisms and capabilities, with some discussion of process approaches and applications. This book puts the fundamentals of activated carbon treatment, adsorption applications, and design of systems in the context of today's and tomorrow's water quality concerns, presenting the reader with a holistic view of the role of activated carbon in the water treatment process.

The intent of the book organization is to serve the needs of various water utility leaders, managers, and professionals; water treatment scientists and engineers; and water utility consultants in three distinct areas related to planning for and designing activated carbon systems:

> *Part 1, Activated Carbon Adsorption Technologies,* covers fundamentals and is targeted at assisting engineers and students who will use the book to gain a basic understanding and knowledge of activated carbon technologies for drinking water technologies.
>
> *Part 2, Adsorption Applications,* is for those who will benefit from approaches to planning the use of activated carbon treatment. In addition, the numerous case studies presented in part 2 demonstrate how and where activated carbon has been successfully implemented to solve specific water quality challenges.
>
> *Part 3, Design and Procurement of Activated Carbon Systems,* provides practical approaches to designers and system operators for effective and efficient design and use of activated carbon technologies as well as strategies for procuring and implementing the systems.

To address the concerns of sustainability related to the reactivation process, the authors included an appendix on sustainability, illustrating the full life-cycle assessment of activated carbon compared to other options for reducing TOC and complying with the Stage 2 D/DBP Rule. A similar process could be used to evaluate removal of micropollutants, comparing activated carbon to technologies such as reverse osmosis membranes and advanced oxidation processes using ozone.

Seventeen case studies comprise appendix B at the end of this book. These case studies will be useful to those readers seeking further practical information and experience from others using activated carbon technologies to improve the quality of their drinking water.

The book is not intended to be a textbook, although instructors can use portions of it to give students information on the basic mechanisms of the technology and practical guidance for training them as practicing engineers. It is assumed that different readers of the book will seek out relevant sections of the book as their needs dictate. Consequently, the book is written such that each of the three parts could be useful for a given audience without detailed study of the remainder.

List of Abbreviations and Acronyms

AC activated carbon
AOC assimilable organic carbon
AOP advanced oxidation process
AWWA American Water Works Association
BAC biologically enhanced activated carbon
BAF biologically active filter
BAT best available technology
BDOC biodegradable dissolved organic carbon
BOM biodegradable organic matter
BTEX benzene, toluene, ethyl benzene, and xylene
BV bed volume
BWWB Water Works Board of the City of Birmingham
CAP Central Arizona Project
CCL Contaminant Candidate List
CCL2 second Contaminant Candidate List
CCL3 third Contaminant Candidate List
CFSTR continuous flow stirred tank reactor
CGTF Central Ground Water Treatment Facility
CIP capital improvements program
CLSA closed-loop stripping analysis
CM construction manager
CMBR completely mixed batch reactor
CMWC Consolidated Mutual Water Company
CSO combined sewer overflow
cVOCs carcinogenic volatile organic compounds
D/DBP Disinfectants and Disinfection By-products
DBP disinfection by-product
DDT dichlorodiphenyl trichloroethane
DHS Department of Health and Safety (California)
DOC dissolved organic carbon
DOM dissolved organic matter
EBCT empty bed contact time
EDC endocrine disrupting compound
EfOM effluent organic matter
ESWTR Enhanced Surface Water Treatment Rule
EMT external mass transfer
GAC granular activated carbon
GC-MS gas chromatography and mass spectrometry
GCWW Greater Cincinnati Water Works
HAA5 sum of five haloacetic acids
HLR hydraulic loading rate
HNM halonitromethanes
HOCs hydrophobic organic compounds
HSDM homogenous surface diffusion model
IAST ideal adsorbed solution theory
IMT internal mass transfer
ISO International Organization of Standardization
LCA life-cycle assessment
MCL maximum contaminant level
MF microfiltration
MIB 2-methylisoborneol
MIEX® magnetic ion exchange
MSDBA mulitstage diffused bubble aeration
MTBE methyl-tert-butyl-ether
MTZ mass transfer zone
N-DBPs nitrogenous disinfection by-products
NDMA N-nitrosodimethylamine

NDWAC National Drinking Water Advisory Council
NJDEP New Jersey Department of Environmental Protection
NOM natural organic matter
NRC National Research Council
O&M operations and maintenance
OTC odor threshold concentration
PAC powdered activated carbon
PAH polycyclic aromatic hydrocarbon
PCB polychlorinated biphenyl
PCE perchlorethylene
PD-RSSCT proportional diffusivity RSSCT
PFOA perfluorooctanoic acid
PFR plug flow reactor
PhAC pharmaceutically active compound
PPCP pharmaceuticals and personal care products
PSDM pore and surface diffusion model
pzc point-of-zero-charge
RSSCT rapid small-scale column test
SAB Science Advisory Board
SCADA supervisory control and data acquisition
SDS simulated distribution system
SDWA Safe Drinking Water Act
SOCs synthetic organic chemicals
SUVA specific ultraviolet absorbance
T&O taste- and odor-causing
TCE trichloroethylene
TDS total dissolved solids
TOC total organic carbon
TTHMs total trihalomethanes
TTHMFP TTHM formation potential
UCMR Unregulated Contaminant Monitoring Rule
UF ultrafiltration
USEPA United States Environmental Protection Agency
USGS US Geological Society
UV ultraviolet
UVA ultraviolet absorbance
VOCs volatile organic compound
WQMP Water Quality Master Plan
WTP water treatment plant
WWTP wastewater treatment plant