IntechOpen

Ozonation

New Aspects

Edited by Murat Eyvaz, Ahmed Albahnasawi,
Ercan Gürbulak and Ebubekir Yüksel

Ozonation - New Aspects

Edited by Murat Eyvaz,
Ahmed Albahnasawi, Ercan Gürbulak
and Ebubekir Yüksel

Published in London, United Kingdom

Ozonation - New Aspects
http://dx.doi.org/10.5772/intechopen.104055
Edited by Murat Eyvaz, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel

Contributors
Ahmed Albahnasawi, Alexandr A. Berlin, Alexey L. Iordanskii, Anatoly A. Olkhov, Anuar Manuel Badillo Olvera, Carlos Martín Enriquez-Castro, César Guzmán Martínez, Ebubekir Yüksel, Ercan Gürbulak, Mahesh Navnath Pharande, Manuel Pérez Nafarrate, Marina L. Konstantinova, Michael David, Mohd Haniff Ibrahim, Murat Eyvaz, Olga Alexeeva, Sevia Mahdaliza Idrus, Shivangi Omer, Tay Ching En Marcus, Thirumal Chandran, Valentina Siracusa

© The Editor(s) and the Author(s) 2024

The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).

Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution 3.0 Unported License which permits commercial use, distribution and reproduction of the individual chapters, provided the original author(s) and source publication are appropriately acknowledged. If so indicated, certain images may not be included under the Creative Commons license. In such cases users will need to obtain permission from the license holder to reproduce the material. More details and guidelines concerning content reuse and adaptation can be found at http://www.intechopen.com/copyright-policy.html.

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2024 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, 167-169 Great Portland Street, London, W1W 5PF, United Kingdom

For EU product safety concerns: IN TECH d.o.o., Prolaz Marije Krucifikse Kozulić 3, 51000 Rijeka, Croatia, info@intechopen.com or visit our website at intechopen.com.

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Ozonation - New Aspects
Edited by Murat Eyvaz, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel
p. cm.
Print ISBN 978-1-83768-928-6
Online ISBN 978-1-83768-929-3
eBook (PDF) ISBN 978-1-83768-930-9

If disposing of this product, please recycle the paper responsibly.

We are IntechOpen, the world's leading publisher of Open Access books

Built by scientists, for scientists

7,300+
Open access books available

192,000+
International authors and editors

210M+
Downloads

156
Countries delivered to

Our authors are among the
Top 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Meet the editors

Dr. Murat Eyvaz is an associate professor in the Environmental Engineering Department, at Gebze Technical University, Türkiye. His research interests are applications in water and wastewater treatment facilities, electrochemical treatment processes and filtration systems at the laboratory and pilot scale, membrane processes (forward osmosis, reverse osmosis, membrane bioreactors), membrane manufacturing methods (polymeric membranes, nanofiber membranes, electrospinning), spectrophotometric analyses (UV, atomic absorption spectrophotometry), and chromatographic analyses (gas chromatography, high-pressure liquid chromatography). He has coauthored many journal articles and conference papers and has taken part in many national projects. He serves as an editor for 50 journals and a reviewer for 120 journals indexed in SCI, SCI-E, and other indexes. He has four patents on wastewater treatment systems to his credit.

Dr. Ahmed Albahnasawi is a research fellow in the Environmental Engineering Department, at Gebze Technical University, Türkiye. His graduate work focused on the investigation of the treatability of sequential anoxic–aerobic batch reactors followed by ceramic membranes for textile wastewater treatment. Based on his Ph.D. research, Dr. Albahnasawi has published three journal articles and participated in three international conferences. Recently, his research interests have included the application and design of microbial fuel cells integrated with Fenton oxidation for industrial wastewater treatment, solid waste management, and monitoring of organic micropollutants by both chromatographic and spectrophotometric analyses.

Dr. Ercan Gürbulak is a research associate in the Environmental Engineering Department, at Gebze Technical University, Türkiye. He received his bachelor's degree in environmental engineering at Marmara University, Türkiye, in 2005. He obtained both an MSc and Ph.D. from Gebze Technical University in 2008 and 2019, respectively. His research interests are the application and design of hydrothermal processes for industrial wastewater treatment and solid waste management and the monitoring of organic micropollutants by both chromatographic and spectrophotometric analyses.

Prof. Ebubekir Yüksel is a faculty member of the Environmental Engineering Department, at Gebze Technical University, Türkiye. He received his bachelor's degree in civil engineering from İstanbul Technical University, Türkiye, in 1992. He also obtained an MSc and Ph.D. from the same university in 1995 and 2001, respectively. His research interests are applications in water and wastewater treatment facilities, electrochemical treatment processes, and filtration systems at the laboratory and pilot scale, watershed management, flood control, deep sea discharges, membrane processes, spectrophotometric analyses, chromatographic analyses, and geographic information systems. He has coauthored numerous journal articles and conference papers and has taken part in many national projects. He has published more than 30 peer-reviewed publications in journals indexed in SCI, SCI-E, and other indexes. He has one patent on pump/turbine design, three on wastewater treatment systems, and one patent application on wastewater treatment systems.

Contents

Preface **XI**

Chapter 1 **1**
Introductory Chapter: Ozonation – Applications and Limitations
by Murat Eyvaz, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel

Chapter 2 **7**
Emerging Technologies in Water Treatment: Recent Advances
by Carlos Martín Enríquez Castro, Manuel Pérez Nafarrate, Anuar Manuel Badillo Olvera and César Guzmán Martínez

Chapter 3 **37**
Paraox Advanced Oxidation: An "Effective" Wastewater Treatment Process for Complex Organic Molecules Contamination
by Thirumal Chandran, Mahesh Navnath Pharande and Shivangi Omer

Chapter 4 **63**
Ozonation of Non-Woven Ultrathin Fibrous Biomaterials for Medical and Packaging Implementations
by Olga Alexeeva, Valentina Siracusa, Marina L. Konstantinova, Anatoliy A. Olkhov, Alexey L. Iordanskii and Alexandr A. Berlin

Chapter 5 **83**
Simulation of Ozone Gas Absorption Cross-Section: A Concentration-Based Analysis for Green Communication
by Michael David, Mohd Haniff Ibrahim, Sevia Mahdaliza Idrus and Tay Ching En Marcus

Preface

Water pollution is still a pressing global concern as industrialization, urbanization, and population growth continue to worsen the quality of water resources. In response to this challenge, ozonation has emerged as a promising advanced treatment technology. Over the years, ozonation has proven to be highly effective in the removal of a wide range of contaminants from water, offering several advantages over traditional methods. Its ability to oxidize persistent organic pollutants, eliminate pathogens, and minimize the production of harmful by-products has positioned ozonation at the forefront of water and wastewater treatment innovations. This book, *Ozonation – New Aspects*, provides a comprehensive overview of the current research, technological advancements, and practical applications of ozonation in the field of water treatment. The five chapters compiled here have been meticulously authored by experts from various backgrounds, each offering unique insights into the multifaceted uses of ozonation.

The introductory chapter lays the foundation by exploring the chemistry, kinetics, and operational principles of ozonation, highlighting its ability to degrade contaminants that are resistant to conventional treatments. The authors also present a detailed analysis of the limitations of ozonation, including its energy-intensive processes and potential for the formation of secondary by-products like bromate. Nevertheless, recent advancements in hybrid ozonation technologies, which combine ozone with other treatment processes, are showing promising results in overcoming these challenges. In the second chapter, the focus shifts to emerging technologies that complement and enhance ozonation. Here, the authors discuss electrocoagulation, cavitation, and other advanced oxidation processes that have gained attention for their ability to work synergistically with ozonation to improve treatment efficiency. The integration of these techniques not only extends the range of contaminants that can be treated but also makes the ozonation process more energy-efficient and environmentally sustainable.

The third chapter explores how paraox-advanced oxidation is applied to treat complex organic pollutants. It highlights the flexibility of paraox technologies, especially in addressing challenging substances like nitro-phenols and other toxic organic compounds, emphasizing the wide-ranging potential of ozonation in environmental treatment processes. The use of hydroxyl radicals generated through ozonation, combined with other catalysts, highlights the potential of this technology for mineralizing pollutants into harmless by-products like carbon dioxide and water. Chapter 4 takes a closer look at the specific use of ozonation in the textile industry, focusing on its role in reducing wastewater pollutants. The nonwoven fabric industry, which produces significant amounts of effluent rich in dyes and chemicals, has found ozonation to be an invaluable tool for reducing the environmental footprint of textile manufacturing. The chapter presents detailed simulations and studies on how ozone interacts with various textile effluents, providing valuable insights into its effectiveness in this domain.

The final chapter investigates the impact of ozone concentration on its absorption cross-section in the visible spectrum. The authors present a detailed study using simulations to explore how ozone concentration influences its effectiveness in various industrial applications. By understanding the relationship between concentration and absorption cross-sections, this chapter sheds light on the optimization of ozone dosage for maximum efficiency, a crucial consideration for both small-scale and large-scale industrial applications. As the field of water treatment continues to evolve, the importance of sustainable and effective solutions cannot be overstated. Ozonation, with its proven history and ongoing innovations, is positioned to play an increasingly vital role in addressing the challenges of water pollution. From industrial effluents to municipal wastewater, the versatility of ozonation offers a glimpse into a future where clean and safe water can be more easily achieved for all.

It is my sincere hope that this book will serve as a valuable resource for both researchers and practitioners in the field of water treatment. Whether you are a seasoned professional or a newcomer to the world of ozonation, the knowledge and insights shared in these pages will provide a solid foundation for understanding the potential of ozonation technologies. By exploring both the opportunities and limitations of this treatment process, we can collectively work toward developing more efficient, cost-effective, and environmentally friendly solutions to safeguard our water resources.

Finally, I would like to express my deepest gratitude to the contributors and collaborators who made this book possible. Their expertise, dedication, and innovative spirit have enriched this work, and I am confident that their contributions will inspire future research and development in the field of ozonation and beyond.

Murat Eyvaz
Associate Professor,
Department of Environmental Engineering,
Gebze Technical University,
Kocaeli, Turkey

Dr. Ahmed Albahnasawi and Dr. Ercan Gürbulak
Department of Environmental Engineering,
Gebze Technical University,
Kocaeli, Turkey

Ebubekir Yüksel
Professor,
Department of Environmental Engineering,
Gebze Technical University,
Kocaeli, Turkey

Chapter 1

Introductory Chapter: Ozonation – Applications and Limitations

Murat Eyvaz, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel

1. Introduction

Water pollution has become a major environmental concern due to the increasing industrialization, urbanization, and population growth worldwide. This has led to the development of advanced technologies for the treatment of water and wastewater. One such technology is ozonation, which has gained popularity in recent years due to its effectiveness in removing pollutants and disinfecting water, its ability to break down compounds resistant to other treatment methods, and the lack of harmful by-products generated during the treatment process [1].

This book aims to provide an in-depth review of the latest research and developments in ozonation technology. The book is divided into several sections that cover topics such as the fundamental chemistry and kinetics of ozonation, the design and operation of ozone generation and delivery systems, the optimization of ozonation processes for different applications, and the environmental and economic aspects of ozonation. The chapters in this book are written by leading experts in the field, and they provide a comprehensive overview of the state-of-the-art in ozonation technology.

2. Principles of ozonation

Ozonation involves the use of ozone gas (O_3) to oxidize various contaminants present in water, including organic matter, pathogens, and inorganic compounds. Ozone is a powerful oxidant that reacts rapidly with pollutants, transferring one of its oxygen atoms to the contaminant, resulting in oxidation [2]. The oxidation process breaks down the contaminant into simpler and less harmful compounds, such as carbon dioxide, water, and mineral acids.

Ozone can be generated by several methods, including corona discharge, electrolytic ozone generation, and ultraviolet light. Among these methods, corona discharge is the most used method for industrial applications due to its high efficiency and low operating costs. The corona discharge method involves passing air or oxygen through a high-voltage electrical field, resulting in the generation of ozone. The effectiveness of ozonation in removing pollutants depends on several factors, such as the concentration and type of contaminants, the pH of the water, and the ozone dosage.

Higher concentrations of pollutants and lower pH levels require a higher ozone dosage to achieve effective removal. The pH of the water also affects the formation of by-products during ozonation. At low pH, the formation of bromate increases, which can be harmful to human health. Thus, the pH of the water must be carefully monitored during ozonation [3].

3. Applications of ozonation in water and wastewater treatment

Ozonation has been used for the treatment of various water sources, including surface water, groundwater, and wastewater. In surface water treatment, ozonation is used to remove organic matter, reduce taste and odor, and disinfect water [1]. Ozone is effective in removing organic matter that is not easily biodegradable by microorganisms in conventional treatment processes. It also breaks down compounds responsible for taste and odor, such as geosmin and 2-methylisoborneol (MIB), which are produced by algae and bacteria in water. Ozonation is also effective in disinfecting water by inactivating pathogens, such as bacteria and viruses.

The use of ozonation in groundwater treatment has been shown to effectively remove iron and manganese, reduce the formation of disinfection by-products, and improve the overall quality of water [4, 5]. Iron and manganese are naturally occurring contaminants in groundwater that cause esthetic problems, such as staining of laundry and plumbing fixtures. Ozonation converts these contaminants into insoluble forms that can be easily removed by filtration. The use of ozonation also reduces the formation of disinfection by-products, such as trihalomethanes (THMs), which are formed when chlorine is used for disinfection. THMs are carcinogenic and have been linked to adverse health effects.

In wastewater treatment, ozonation has been used to remove organic and inorganic contaminants, reduce the levels of pathogens, and improve the quality of effluent. Ozonation can be used as a pre-treatment step to enhance the efficiency of conventional treatment methods, such as biological treatment and activated carbon adsorption. Ozonation breaks down complex organic compounds into simpler forms that can be more easily biodegraded by microorganisms in biological treatment processes. Inorganic compounds, such as nitrogen and phosphorus, can also be removed by ozonation through oxidation and precipitation. The use of ozonation as a pre-treatment step has been shown to increase the removal efficiency of conventional treatment methods and reduce the formation of disinfection by-products [6].

Ozonation can also be used as a post-treatment step to disinfect wastewater and remove trace contaminants that may have survived the conventional treatment process. Ozonation has been shown to be effective in inactivating viruses, bacteria, and protozoa in wastewater [7]. It also breaks down trace organic contaminants, such as pharmaceuticals and personal care products, which are resistant to conventional treatment methods.

4. Benefits and limitations of ozonation

Ozonation offers several benefits over conventional treatment methods, such as chlorine disinfection and biological treatment. Ozonation is effective in removing a wide range of contaminants, including those resistant to other treatment methods, and does not produce harmful disinfection by-products. Ozonation is also a fast and efficient process, with reaction times typically ranging from a few seconds to a few minutes. The process is also easily scalable, making it suitable for both small and large-scale treatment facilities.

However, ozonation also has some limitations. The initial capital and operating costs of ozonation systems are higher than those of conventional treatment methods, such as chlorination. The high cost is mainly due to the requirement for specialized equipment and the high energy consumption during ozone generation. Ozonation also requires careful monitoring of the pH and dissolved organic matter levels to prevent the formation of harmful by-products, such as bromate. Additionally, ozonation may not be effective in removing some contaminants, such as dissolved solids and heavy metals, which require other treatment methods.

5. Recent advancements in ozonation research

Recent research has focused on improving the efficiency and effectiveness of ozonation through the development of new technologies and processes. One such technology is the use of hybrid systems, which combine ozonation with other treatment methods, such as biological treatment and membrane filtration. Hybrid systems have been shown to increase the removal efficiency of contaminants and reduce the formation of by-products [8].

Another area of research is the optimization of ozone dosage and reaction time to improve the efficiency of ozone. Researchers have developed mathematical models to predict the optimal ozone dosage and reaction time based on the type and concentration of contaminants present in the water [9]. The use of these models can help optimize the ozonation process and reduce operating costs.

6. Conclusion

Ozonation is a powerful and effective technology for the treatment of water and wastewater. It offers several benefits over conventional treatment methods, such as chlorine disinfection and biological treatment, including the ability to remove a wide range of contaminants and the lack of harmful by-products. However, ozonation also has some limitations, such as the high initial capital and operating costs, and the requirement for careful monitoring of the pH and dissolved organic matter levels. Recent advancements in ozonation research have focused on improving the efficiency and effectiveness of the method through the development of new technologies and processes. Overall, ozonation is a promising technology for the treatment of water and wastewater, and its use is expected to increase in the future as water pollution continues to be a major environmental concern.

This book is intended to serve as a valuable resource for researchers, engineers, and practitioners who are interested in ozonation technology and its applications. We hope that this book will inspire new ideas and approaches to improving the efficiency and effectiveness of ozonation, and that it will contribute to the development of more sustainable and cost-effective water treatment solutions.

Author details

Murat Eyvaz*, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel
Department of Environmental Engineering, Gebze Technical University, Kocaeli, Turkey

*Address all correspondence to: meyvaz@gtu.edu.tr

IntechOpen

© 2023 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Langlais B, Reckhow DA, Brink DR, editors. Ozone in Water Treatment: Application and Engineering. Newyork, USA: Routledge; 2019

[2] Coha M, Farinelli G, Tiraferri A, Minella M, Vione D. Advanced oxidation processes in the removal of organic substances from produced water: Potential, configurations, and research needs. Chemical Engineering Journal. 2021;**414**:128668. DOI: 10.1016/j.cej.2021.128668

[3] Wei C, Zhang F, Hu Y, Feng C, Wu H. Ozonation in water treatment: The generation, basic properties of ozone and its practical application. Reviews in Chemical Engineering. 2017;**33**(1):49-89. DOI: 10.1515/revce-2016-0008

[4] Aziz HA, Shakr SNM, Akbar NA, Alazaiza MYD. The removal efficiency of iron and manganese from pre-ozonated groundwater using limestone filter. Water Quality Research Journal. 2020;**55**(2): 167-183. DOI: 10.2166/wqrj.2020.014

[5] Sukmilin A, Sangsirimongkolying R. Treatment of iron from groundwater by ozonation: Influence of hardness as a scavenger. Applied Environmental Research. 2021;**43**(2):106-115. DOI: 10.35762/AER.2021.43.2.8

[6] Papageorgiou A, Stylianou SK, Kaffes P, Zouboulis AI, Voutsa D. Effects of ozonation pretreatment on natural organic matter and wastewater derived organic matter – Possible implications on the formation of ozonation by-products. Chemosphere. 2017;**170**:33-40. DOI: 10.1016/j.chemosphere.2016.12.005

[7] Lim S, Shi JL, von Gunten U, McCurry DL. Ozonation of organic compounds in water and wastewater: A critical review. Water Research. 2022;**213**:118053. DOI: 10.1016/j.watres.2022.118053

[8] von Gunten U. Ozonation of drinking water: Part I. Oxidation kinetics and product formation. Water Research. 2003;**37**(7):1443-1467. DOI: 10.1016/S0043-1354(02)00457-8

[9] Rekhate CV, Shrivastava JK. Decolorization of azo dye solution by ozone based advanced oxidation processes: Optimization using response surface methodology and neural network. Ozone: Science & Engineering. 2020;**42**(6):492-506. DOI: 10.1080/01919512.2020.1714426

Chapter 2

Emerging Technologies in Water Treatment: Recent Advances

Carlos Martín Enríquez Castro, Manuel Pérez Nafarrate, Anuar Manuel Badillo Olvera and César Guzmán Martínez

Abstract

Ozone, a triatomic oxygen molecule, is a powerful oxidant generated by water electrolysis or produced in situ using the corona discharge method. Typical applications in water treatment involve the disinfection, disposal of virus, bacteria, and hydrogen sulfide removal and are responsible for odorous compounds in septage tanks and oxidation lagoons. Recently, electrocoagulation and cavitation have evolved to increase the efficiency of ozone gas disinfection. Electrocoagulation (EC) permits the sanitation of wastewater, the destruction of oil-water emulsions, and heavy metals present in mining waste and manufacturing industry. EC is useful when traditional disinfection methods using chemical agents or biological treatment is not completely efficient. Using the EC technology proposed by Reingeniería en Saneamiento Ltd., replacement of sacrifice electrodes is not estimated. Cavitation and ozone systems, as beneficial processes in water treatment technology are supported by electroflotation, electrocoagulation, and electrochemistry in urban wastewater plants to accomplish effective solutions in different processes. Along with the chapter, how modular plants can be designed to achieve the correct purification system based on a previous diagnosis of the process is explained. Finally, due to complexity of treatment process, automation need to advance from manual control to programmable logic controllers if control architectures for water treatment system advance in the same way the depuration process is properly controlled.

Keywords: ozone, electrolysis, electrocoagulation, cavitation, water treatment

1. Introduction

Ozone is a natural gas created from oxygen atoms. The oxygen molecule is made up of two oxygen atoms. These oxygen molecules are broken into atoms by corona discharge during electrical storms or by UV light from the Sun [1]. Individual oxygen atoms cannot exist alone without reassembling back into diatomic oxygen molecules. During this recombination step, some atoms will regroup into loosely bound triatomic oxygen. This new molecule is called ozone, ozone is a very strong oxidant and an ideal chemical-free purification and disinfectant agent. Ozone is often misdiagnosed as low-altitude pollution [2]. This could not be farther from the truth. In fact, ozone breaks down pollutants and should be welcomed when it is in the air. The most effective way to produce ozone commercially is through the use of corona discharge [3].

Ozone is dissolved thirteen times faster in water than oxygen and acts immediately, instead of using chlorine. Several functions such as dispatch of viruses, bacteria, molds, spores, and algae make this chemical agent very efficient [4]. Plenty of applications in the industry and home are extensive: ozone oxidizes nitrites to nitrates, organic nutrients and hydrogen sulfide are dissolved, color and odor are vanished, BOD can decrease, and dissolved oxygen is increased. Nowadays, it can be inferred that water treatment is the most beneficial.

1.1 How does ozone work?

When ozone is exposed to a bacteria or a virus, it immediately destroys the cell membrane. This happens in less than a second. Ozone is an oxidizing agent and when it encounters any odor molecule, oxidation occurs (chemical combustion) as shown in **Figure 1**. Disinfection by triatomic oxygen (ozone) occurs through the rupture of the cell wall. This is a more efficient method than chlorine, which relies on diffusion into cell protoplasm and inactivation of enzymes. An ozone level of 0.4 ppm for four minutes has been shown to kill any bacteria, viruses, mold, and mildew. When the effectiveness of ozone as a disinfectant was measured, there was little or no disinfection up to a certain dose. At higher levels, the disinfectant effect increases. For complete disinfection, excess or residual ozone must be maintained in the solution to ensure that all living microorganisms have been contacted. No antibiotic that is really effective in the field of virus has been discovered yet. There are indications that DNA viruses such as herpes are implicated in human cancers, as they organize the host cell's genetic material to produce new viruses. Ozone will inactivate viruses on contact, even at very low temperatures and residual concentrations. In the case of polio, just 0.012 ppm kills all viral cells in less than 10 seconds. Mold and mildew are easily controlled by the ozone present in the air and in the water. Giardia and Cryptosporidium cysts are susceptible to ozone but are not affected by normal chlorine levels.

As can be seen in **Figure 2**, ozone reacts with a bacterium, and a cracking process inside the cell structure is initiated [1]. Ozone penetrates into the periphery of the cell wall [2]. The ozone penetrates and creates a hole in the bacterial wall [3]. The ozone molecule in the bacterial cell structure is inserted [4]. Magnification of the bacterial cell after contact with the ozone molecules [5]. Destruction of the cell after ozone

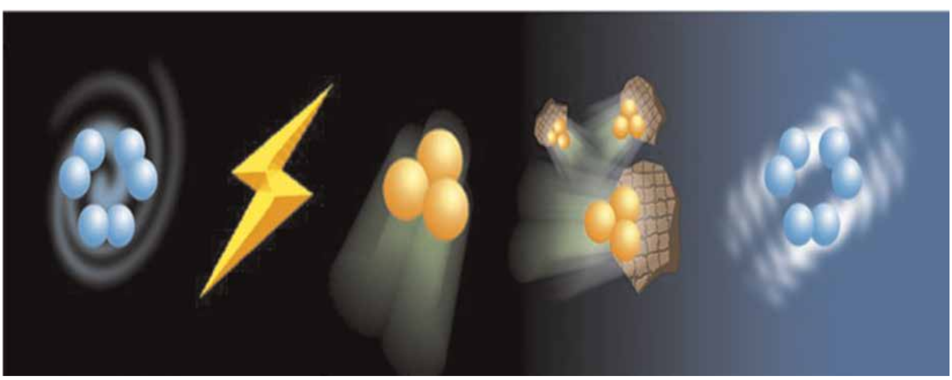


Figure 1.
Mechanism of ozone in touch with an electric source to produce pure oxygen. (adapted from www.ozonesolutions.com).

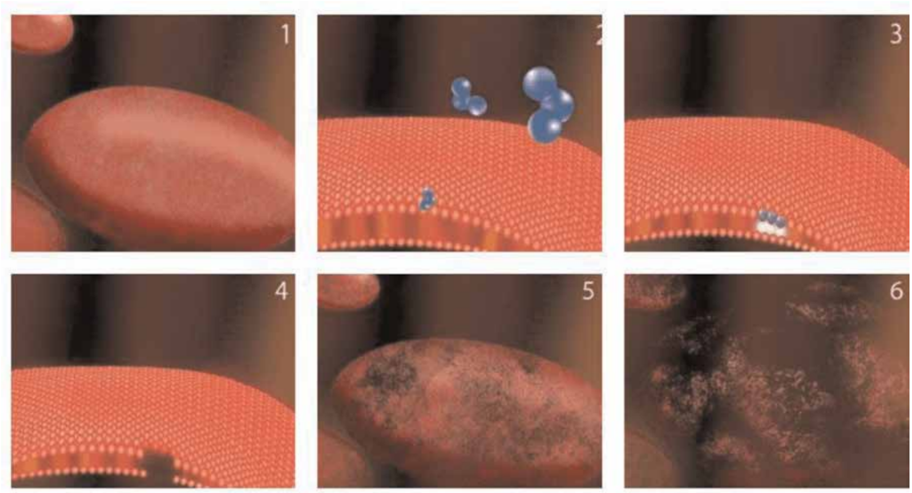


Figure 2.
Detail of ozone action in the bacterial cell. https://my.medklinn.com/knowledge_centre/effect-of-ozone-on-bacteria/.

action. Research investigations to destroy gram-negative and gram-positive bacteria's have been conducted [2, 3, 5]. A procedure to destroy enterobacterias such as *E. coli* at 95°F, using ozone, requires an ozone range between 0.1 and 0.5 mg/l and maintaining an adequate redox potential to reach a higher disinfection efficiency [6].

The mechanisms of ozone bacterial destruction need to be further elucidated. It is known that the cell enveloped by bacteria are made of polysaccharides and proteins and that in Gram-negative microorganisms, fatty acid alkyl chains and helical lipoproteins are present. In acid-fast bacteria, such as *Mycobacterium tuberculosis*, on third to one-half of the capsule is formed of complex lipids (esterified mycolic acid, in addition to normal fatty acids), and glycolipids (sulfolipids, lipopolysaccharides, mycosides, and trehalose mycolates). The high lipid content of the cell walls of these ubiquitous bacteria may explain their sensitivity, and eventual demise, subsequent to ozone exposure. Ozone may also penetrate the cellular envelope, directly affecting cytoplasmic integrity, and disrupting any one of numerous levels of its metabolic complexities.

1.2 Characteristics of ozone as a disinfectant agent

The effect of ozone to eliminate pathogens has been corroborated for several decades. Its killing action on bacteria, viruses, fungi, and many species of protozoa serves as the basis for its growing use in disinfecting municipal water supplies in cities around the world. Bacteria are microscopic so-called tiny single-celled creatures that have a primitive structure. They absorb food and release metabolic products, and multiply by division. The body of the bacterium is sealed by a relatively solid cell membrane. Their life processes are controlled by a complex enzyme system. Ozone interferes with the metabolism of bacterial cells, most likely by inhibiting and blocking the functioning of the enzyme control system. A sufficient amount of ozone passes through the cell membrane, and this leads to the destruction of bacteria. Viruses are small, self-contained particles built of crystals and macromolecules. Unlike bacteria, they multiply only within the host cell. Ozone destroys viruses by diffusing through the protein coat in the nucleic acid core, resulting in viral RNA damage. At higher concentrations, ozone destroys the capsid or outer protein shell by oxidation. Indicator bacteria in effluents, namely coliforms and pathogens, such as *Salmonella*, show a marked sensitivity to ozone inactivity. Other bacterial microorganisms susceptible to the disinfecting properties of ozone include *Streptococci, Shigella, Legionella pneumophila, Pseudomonas aerunginosa, Yersinia enterocolitica, Campylobacter jejuni, Mycobacteria, Klebsiella pneumonia*, and *Escherichia coli* [1]. Ozone destroys both aerobic and, more importantly, anaerobic bacteria, which are primarily responsible for the devastating sequelae of complicated infections, as exemplified by pressure ulcers and gangrene.

Ozone is the most oxidizing agent available to man after fluorine. Thanks to its high oxidizing power, ozone is capable of attacking and destroying all kinds of microorganisms such as bacteria, cysts, virus, algae, spores, and protozoa. Several research papers talking about the importance of these topics have been realized previously [1, 7–10]. Ozone used in combination with other emergent technologies decomposes organic substances including detergents, phenols, pesticides, herbicides, and fertilizers; neutralizes inorganic substances such as ammonia, urea, nitrites, cyanides, and arsenic [11]. Numerous families of viruses including poliovirus I and II, human rotaviruses, Norwalk virus, Parvoviruses, and hepatitis A and B, among many others, are susceptible to the virucidal actions of ozone. Most research efforts on virucidal effects of ozone have centered upon ozone's propensity to break apart lipid molecules at sites of multiple bond configuration. Indeed, once the lipid envelope of the virus is fragmented, its DNA or RNA core cannot survive. Non-enveloped viruses (Adenoviridae, Picornaviridae, namely poliovirus, Coxsackie, echovirus, rhinovirus, hepatitis A and E, and Reoviridae (Rotavirus)), have also begun to be studied. Viruses that do not have an envelope are called "naked viruses." They are constituted of a nucleic acid core (made of DNA or RNA) and a nucleic acid coat, or capsid, made of protein. Ozone, however, aside from its well-recognized action upon unsaturated lipids, can also interact with certain proteins and their constituents, namely amino acids. Indeed, when ozone comes in contact with capsid proteins, protein hydroxides and protein hydroxides and protein hydroperoxides are formed.

Viruses have no protection against oxidative stress. Normal mammalian cells, on the other hand, possess complex systems of enzymes (i.e., superoxide dismutase, catalase, and peroxidase) that tend to ward off the nefarious effects of free radical species and oxidative challenge. It may thus be possible to treat infected tissues with ozone, respecting the homeostasis derived from their natural defenses, while neutralizing offending and attacking pathogens devoid of similar defenses. The enveloped viruses are usually more sensitive to physicochemical challenges than naked virions. Although ozone's effects upon unsaturated lipids are one of its best-documented biochemical action, ozone is known to interact with proteins, carbohydrates, and nucleic acids. This becomes especially relevant when ozone inactivation of non-enveloped virions is considered. Fungi families inhibited and destroyed by exposure to ozone include *Candida, Aspergillus, Histoplasma, Actinomycoses*, and *Cryptococcus*. The walls of fungi are multilayered and are composed of approximately 80% carbohydrates and 10% of proteins and glycoproteins. The presence of many disulfide bonds had been noted, making this a possible site for oxidative inactivation by ozone. In all likelihood, however, ozone has the capacity to diffuse through the fungal wall into the organismic cytoplasm, thus disrupting cellular organelles. Protozoan microorganisms disrupted by ozone include *Giardia, Cryptosporidium*, and free-living amoebas, namely *Acanthamoeba, Hartmonella*, and *Naegleria*. The antiprotozoal action has yet to be elucidated.

2. Effect of ozone in the treatment of industrial effluents

According to Ostman et al. [12], to reach the scale-up of an adequate ozone treatment system, the following considerations are important: accomplishing the demand for ozone and considering the flow rate on demand, design, and development of all the peripheral equipment necessary to maintain the production process including the ozone generator, pipes and reaction chamber, and the panel control considered can include the instrumentation devices and power unit. Reingeniería en Saneamiento Ambiental Ltd. has evolved in technology transfer offering its products with an uninterrupted improvement philosophy. To increase in the demand for ozone, the concept of modular plants provided in their business proposals is considered. Another point in the prototype design is to recall the primary purpose of the model. In **Figure 3**, it is displayed a specific model to comply with the specifications of the construction industry.

According to the operational principle of the TRIO3® injector, when pressurized operating water enters the interior of the injector, it is compressed in the injection chamber and changes into a high-velocity jet of water. The increased velocity through the injection chamber results in a decrease in pressure, thus allowing gas (ozone or air) to be drawn through the suction port and entrained in the water stream. As the water stream moves toward the injector outlet, its speed is reduced and it exits at a lower pressure than the injector inlet pressure. TRIO3 has invented and manufactured an injector superior to anything on the market today. The size of the bubbles allows the ozone gas to have full contact with the water and to control the release of the gas. The excellent mass transfer of this injector allows more "work" with less ozone, saving the customer money. As the ozone gas enters the water stream, it is in the form of small "micro-bubbles," which are aggressively mixed with the water. These "micro-

Figure 3.
Components of a water treatment plant for a housing complex of 20 houses and 100 inhabitants (with TRIO3 permitted authorization).

Time (min)	ppm*	% ozone
1	5.78	68
5	6.64	78
10	6.47	78

*Average concentration was 6.29 ppm.

Table 1.
Ozone concentration in the injector using microbubbles.

bubbles" provide an exceptionally large surface area on which ozone can be effectively transferred into the water. A large bubble is 20 mm and has a volume of 4.19 cm^3 and a surface area of 12.6 cm^2. Two hundred and ninety-six small bubbles (3 mm) can be won instead of the big bubble in previous point with a total area of 3.6 cm^2. This is 6.6 times the area of the large bubble. This smaller bubble has better mass transfer, and the process becomes more efficient.

Table 1 shows the operating parameters using a TRIO3® injector. The measured dissolved oxygen concentration was a 150-gallon tank of water in the TRIO3® injector installed, using a baseline of 4.76 ppm and 56% of purity at 73.4°F. The oxygen concentrator uses air drawn from outside the housing through a Solberg replaceable element coarse particle air filter. The integral compressor passes air through a bed of molecular sieves providing 95 ±1% pure oxygen feed gas through the ozone cell. Air passing through the filter is stripped of nitrogen and water vapor to give dry oxygen feed gas. The oxygen concentrator gives a true dew point of −52°C to prevent the formation of HNO_3 (nitric acid) within the ozone cell. Oxygen is regulated for pressure and flow and is set at 6 L/min introduced through stainless steel fittings and Teflon tubing into the ozone cell. The ozone cell is powered by solid-state electronics and is a medium-frequency generator designed to operate at 500 Hz and 50,000 V. In this way, oxygen passing through the ozone cell is converted into ozone. Ozone exits the cell through a stainless steel and ozone-proof line to a stainless steel bulkhead that fits into the bottom of the housing and connects to the blower assembly.

2.1 Ozone as a disinfectant agent in municipal waste effluents

Hydrogen sulfide (H_2S), an acutely toxic substance, is immediately lethal at relatively low concentrations. H_2S becomes a health and safety hazard when it combines with carbon dioxide and water vapors as it corrodes plant equipment and piping. When shaken it erupts with such speed that levels of toxicity paralyze the lungs. This eruption occurs when stagnant sewage is shaken by loosening a plug. Wastewater contains up to 6000 ppm. Exposures as low as 300 ppm over a 30 min period will render a person unconscious. Exposure to a concentration of 1000 ppm of H2S in air causes paralysis of the respiratory system, cardiac arrest, and death within minutes. H2S is produced by the action of anaerobic sulfur-fixing bacteria on materials containing sulfur. In low concentrations, hydrogen sulfide smells like rotten eggs. At high concentrations, it desensitizes the sense of smell, and in the nose, it is no longer detectable. H2S is colorless, flammable, heavier than air, soluble in water, and extremely toxic.

Research conducted by the National Institute for Occupational Safety and Health (NIOSH) at three municipal wastewater treatment plants resulted in worker health symptoms of shortness of breath, sore throat, eye irritation, nausea, and diarrhea. Area air samples were collected for H_2S using sensor monitors and data loggers. Hydrogen sulfide concentrations ranged from undetectable to 124 ppm. NIOSH recommended exposure limits for hydrogen sulfide are capped at 10 ppm. This may not be exceeded during any part of the working day. As confirmed by OSHA regulations, 124 ppm H_2S exposure is immediately dangerous to life or health conditions.

Municipal waste effluents (MWE) are present mainly in a big populated city. MWE includes a combination of aromatic compounds, oily discharges, and food industry waste. MWE are hardly degradable by conventional methods, and due to high toxicity have high COD lectures [13]. MWE deposited in waste-activated sludges are oxidized using combined methods such as ozone and electrocoagulation [14, 15]. Next, a first case study was performed at the *Miami Dade County Water and Sewer Department* (WASD) and applied in a Corrosion Control Program to implement the inspection and assessment of several pumping stations of potable water.

2.1.1 Introduction

Identifying and rehabilitating corrosion deterioration in the pump stations of WASD. As part of WASD's corrosion control program, technical personnel inspected approximately 34 pump stations for corrosion damage in recent years under two different projects. As an additional WASD staff performing routine maintenance, 18 pump stations with significant corrosion were also identified. This project provided engineering services for a corrosion inspection and evaluation of the 52 pumping stations. The findings and recommendations are presented in this report.

2.1.2 Objective

The objective of this project was to identify the necessary rehabilitation efforts to repair existing damage and mitigate further corrosion deterioration of each of the pumping stations. A prioritized schedule and preliminary cost estimate for the implementation of recommended corrective actions were also provided.

The realization of this project involved the following tasks:

1. Inspect all pump stations identified by WASD.

2. Evaluate the extent of corrosion based on the inspection results.

3. Identify the necessary measures of rehabilitation and protection against corrosion.

4. Develop cost estimates at the planning level.

5. Prepare a prioritized schedule for implementation.

6. Prepare a report documenting the inspection findings and recommendations.

2.2 Inspection

During the inspections, the extent of the corrosion was documented through photographs. Due to H_2S levels, inspections often included confined space entry procedures, including self-contained breathing apparatus (SCBA). Once the pumping stations were entered, specific assessments of the condition of the station were made, including:

1. The severity of structural corrosion (lack of concrete and exposed rebar).

2. The state of gates, handrails, ventilation, and lighting.

3. The corrosivity of the atmosphere (levels of hydrogen sulfide).

2.2.1 Selection of pumping stations

The selection of the pumping stations, which were inspected as part of this study, was based on the following:

1. An initial list of significant corrosion damage in pump stations identified by the WASD Pump Station Division.

2. Subsequent inspections by the WASD team revealed additional pumping stations with more severe levels of corrosion.

3. Pumping stations identified by the staff crew with significant corrosion damage in the framework were classified in the "Pumping Station Odor Survey Project."

4. The pumping stations inspected under this project are those believed to have the most severe corrosion problems based on available information.

2.2.2 Other considerations

The pump station dry well was also inspected for conditions that could contribute to corrosion. Items of concern included:

1. The general condition of the structure of the dry well, pumps, and electrical components.

2. Suction or discharge ventilation.

3. If a dehumidifier is present and working.

4. If a sump pump is present and working.

5. Some of the criteria that were evaluated included the Corrosion Description (None, Not Remarkable, Apparent Corrosion) and the Corrosion Classification (Depending on the white deposits caused by salts and minerals as well as the damage caused in the structure). **Figure 4** shows a detailed description of the pumping equipment damaged.

The findings of this investigation show that each pumping station presented different levels of deterioration. Even though none of the pumping stations inspected showed significant corrosion in the dry well, it was noted that a dehumidifier was

DOI: http://dx.doi.org/10.5772/intechopen.109063

Figure 4.
Effects of corrosion in pumping stations (WASD Pump Station division permission).

required, which is essential to remove moisture and prevent a corrosive atmosphere in the dry well. In this way, it was possible to reduce this problem. On the other hand, the levels of hydrogen sulfide were monitored to know the aggressiveness of the atmosphere and the speed at which corrosion occurs inside the wet well. Severe corrosion damage can be expected at stations with levels between 1 and 10 ppm. Therefore, these data in combination with physical evidence provide a reasonable basis for determining the corrosion potential at each station. For example, some stations (PS 44 and PS 516) with moderate corrosion damage recorded hydrogen sulfide levels below 1 ppm on the day of inspection, a moderate level of corrosion, and loss of concrete from the walls, which indicates that these concentrations damage the structure of the pumping equipment due to the effect of the gas. The ozone, used at several concentrations (1, 3, and 5%) allowed the elimination of hydrogen sulfide, taking into account the safety problems that this represented. Regarding this point, it is convenient to point out that the entrance of personnel to the wet well is necessary for many pumping stations to carry out routine maintenance operations, such as cleaning of the bar screens, operation of the gate, and maintenance of pressure sensors.

Wet well level and pump suction bells. The safety of operations and maintenance personnel while performing these tasks was a primary concern in the wet well evaluation. The safety of each pump station was assessed based on the condition of the access ladder, work platform, handrails, and wet vent. Repair or replacement of any of the above. **Figure 5** shows the ozone generator used in the experiment.

The second case was developed in Gifford Florida, a facility that TRIO3 had installed and used to demonstrate the effectiveness of removing the odors from a wastewater treatment plant (WWTP). A proposal was suggested to the directive staff of the WWTP to eliminate odors with ozone at a reasonable cost in a 30-day trial.

Two units to prove the ability of ozone were mounted, and a month later three more systems were installed. A main disinfection objective in the workers' office allowed them to work in a clean and odor-free room. The other two were larger units

Figure 5.
Ozone generator (gas bust 2000 displayed with TRIO3 permitted authorization).

installed on the septage tank and in the dewatering building. On the facility, on a daily basis, were taken readings of the hydrogen sulfide levels. During these readings/tests, an MDS MINI responder hydrogen sulfide meter was used. The manual reading in the septage tank is shown in **Figure 6**.

Lectures taken during the trial were between 130 and 700 ppm of hydrogen sulfide. A properly sized machine as quoted herein eliminated 100% of the hydrogen sulfide and methane. The proposed unit treated all five chambers in the septage tank. Since the hydrogen sulfide is the more powerful odor than the methane second, all odors from this area of the plant ceased. Based on the pilot study conducted, an estimation of the septage tank requirements required a Gas Buster unit (as shown previously in **Figure 5**) sufficient to provide a minimum of 10 pounds per day of ozone. **Figure 7** shows the detailed facility monitored.

The dewatering building is the source of several odorous compounds. Therefore, the removal of the liquids and the composition of the solids are a major source of odors. The chief culprit is again hydrogen sulfide. As treated sewage solids are

Figure 6.
Readings taken in Septage tank (with TRIO3 permitted authorization).

Figure 7.
Septage tank with a gas buster unit installed (with TRIO3 permitted authorization).

introduced to the belt press, the liquid in the solids are removed in this facility as shown below in **Figure 8**.

The proposal of the odor control study proposed by TRIO3 in the sludge thickener tanks was a major issue to aboard. Ozone control system in Florida facility included the design and installation of a cover for the tank and interfaced a gas buster system so as to provide a blanket of ozone between the cover and the sludge. The dome designed is shown in **Figure 9**. The reduced loading of the scrubbers with the ozone system enhanced their ability to remove all odors. The loading from the Septage Tanks was virtually zero and the loading from the Dewatering Building was also zero. The scrubber was installed with the addition of ozone to perform as designed.

Figure 8.
Belt press used to treat sewage solids (with TRIO3 permitted authorization).

Figure 9.
Sludge thickener facility (with TRIO3 permitted authorization).

2.3 Evolution of water treatment units with different purposes

One of the characteristics present in the process developed by Reingeniería en Saneamiento Ambiental Ltd. around the last 20 years includes the addition of operative modules in order to fulfill the requirements of the process. **Figure 10a** shows the module installed with ozone and electrochemical oxidation/precipitation unit, reactor tank with measurements of 90 cm width x 1.20 m height. **Figure 10b** displays a complete PLC console; this rack includes a flocculation tank, aeration tank, ozone generator, power supply, and PLC control display.

Ozone molecules reacting with the influent give different qualities of treated water, which can be reached when active compounds (free radicals) react with the polluted mixture of the influent [16]. Therefore, a high quality treated water depends on the concentration of ozone used in the oxidation process as shown in **Figure 11**.

3. Innovative technologies in water treatment

3.1 Electrocoagulation

Electrocoagulation (EC) allows the purification of wastewater that has a high content of salts. To carry out the physicochemical operation of electrolysis, it is necessary to dissolve the compounds by means of electrodes provided with iron or aluminum. Due to this electrolysis reaction of water, hydroxyl compounds are generated [17].

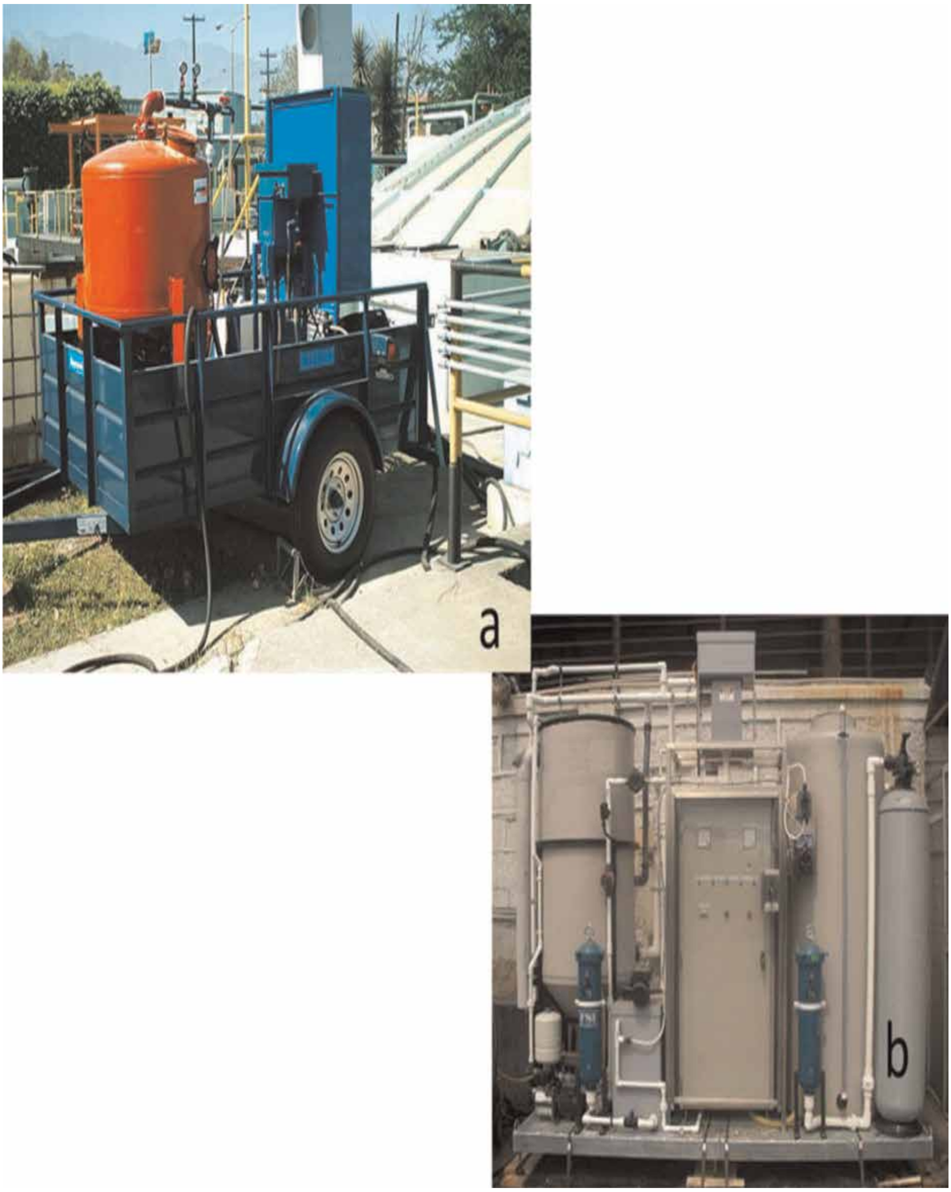


Figure 10.
Mobile unit provided with ozone generator and electrolysis unit (with TRIO3 permitted authorization).

According to Barrera-Diaz [18], EC is effective in the following processes:

1. Remotion of heavy metals such as oxides that pass the Toxicity Characteristic Leaching Procedure (TCLP).

2. EC eliminates successfully suspended and colloidal solids.

3. EC disrupts oil-in-water emulsions.

Figure 11.
Pictures of influent and the evolution in the quality of water for several effluent samples (with TRIO3 permitted authorization).

4. Separation of grease, oil, and lubricants.

5. Extraction and appropriate disposal of organic complexes.

6. EC remotion effectiveness of bacteria in an effective way.

7. Destruction of viruses and microorganisms.

Not many studies mention the EC and ozone to depurate wastewater at the industrial level, and most of the research developed under controlled conditions [11, 17]. Electrocoagulation is effective when we accomplish the following conditions: first, the device generates an electric charge between particles; the electrical layer between both particles must be strong enough to be repelled and prevent agglomeration. Finally, the flocculation capacity to form flocs is monitored. Flocs deposited at the bottom of the deposit are disposed of. Therefore, EC is possible when the process variables such as pH, impelling force, and aggregation level of the coagulant species are monitored correctly [18]. A detailed scheme of what happens in the EC process, as shown in **Figure 12**, is the following.

EC process is useful when the addition of chemical agents, such as chlorine, is not completely efficient as mentioned below:

1. The ions produced in excess during EC do not necessarily increase the number of salts in the influent avoiding a higher quantity of the sludge produced.

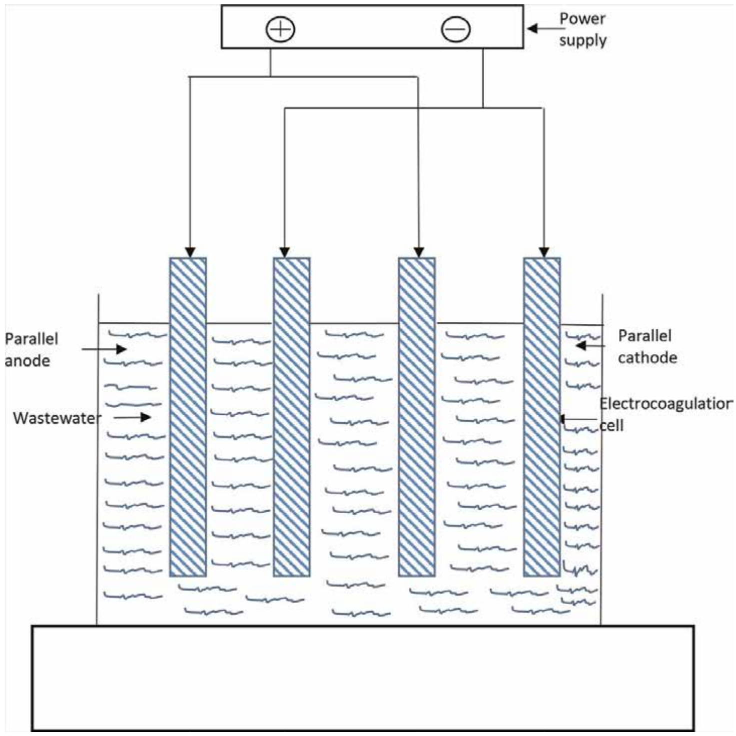


Figure 12.
Schematic design of electrocoagulation reactor (according to Mohammad Ahmadian design).

2. It is necessary to generate a higher electric activity to eliminate the contaminants effectively, removing them due to the generation of gas bubbles (H_2 and O_2) and dragging them to the surface.

3. A dissolved air flotation clarifier (DAF-type unit) line is installed to increase the flotation efficiency. In electroflocculation, the removal of contaminants is favored because the gas bubbles generated in the system (H_2 and O_2) drag them, so they tend to float on the surface.

The different variables involved induce three recurrent procedures but at the same time different from each other, as mentioned in Appendix 1. The theoretical foundation of electrocoagulation is that precipitation takes place at the same time as colloid destabilization. On the other hand, chemical coagulation consists of the formation of sludge due to the union of colloids, forming masses of considerable size, to later separate them from the water by adding more chemicals such as Aluminum Sulfate, Ferric Chloride, among others. The masses of colloids are formed by the contact between the colloids, this is achieved mainly by the movement of the liquid, due to electrical phenomena, such as the presence of ions of opposite charge to that of the colloids, action of hydrogens, and others. It is important to mention that the water is subjected to electrolysis, which is favored by the presence of dissolved salts, which enable the conduction of electricity and are present in all wastewater and industrial water. Due to this, a release of gaseous Hydrogen and Oxygen is produced in their respective electrodes. When these gases rise to the surface, they cause three phenomena: (1) Quick separation of colloids from the electrode, preventing it from getting

Energy consumption	Energy consumption varies (depending on the type of water to be treated).
Electrode wear	With our Technology, replacement of the electrodes is not estimated, since they are made of food grade 316 L stainless steel, so there is no wear on them, so it does not require washing the electrodes with acid to its descaling of salts
Operating conditions	The electrocoagulation system works automatically, through electronic controls that regulate current and voltage, according to changes in the quality of the wastewater to be treated, given by its resistivity.
Sludge production	The production or generation of sludge is directly related to the level of contamination of the residual water. In any case, the generation of sludge is less than a conventional chemical or biological system. A more compact sludge is obtained.

Table 2.
Process variables involved in electrocoagulation.

dirty (cleaning); (2) Dragging of destabilized colloids to the surface forming a cream, allowing not only extraction by classical sedimentation but also by flotation, and; (3) Due to the gas bubbles, ascending and descending currents of the solution are produced, causing a better contact surface, thus causing an increase in the destabilization efficiency. This "spontaneous" agitation avoids "mechanical" agitation (no external agitation needed).

Technical scope of electrocoagulation.

The electrocoagulation process can be defined as the destabilization of suspended or dissolved chemical species present in a solution, product of the application of an electrical potential difference through a cathode–anode system immersed in the water solution to be treated. As a consequence, and during the said electrolytic process, the cationic species produced at the anode enter the solution, reacting with the other species, forming flocs, and precipitating the respective hydroxides. Unlike chemical, coagulation is the origin of the coagulant.

Technical aspects of electrocoagulation operation.

The operating conditions of an electrocoagulation system are highly dependent on the chemical conditions, pH, particle size of the water to be treated, and especially its conductivity. The general treatment of wastewater requires low voltage applications (<50 Volts) with variable amperage, according to the chemical characteristics of the water. **Table 2** shows several technical aspects to consider when using electrocoagulation.

3.2 Comparative analysis of electrocoagulation vs. biological treatment

- The electrocoagulation system applied to wastewater, compared to conventional biological systems, requires a smaller surface (between 50 and 60% less).

- Electrocoagulation residence times are 10 to 60 s, compared to biological systems that require 12 to 24 h.

- They are compact units, easy to operate, with lower energy consumption and sludge production (more compact) than conventional biological systems.

- The electrocoagulation cells are made of PVC, or high-density polyethylene and are installed on the ground. Therefore, they do not require major civil works, such as chemical and biological systems.

- Investment costs are 50% lower than biological systems.
- Electricity consumption per m^3 of treated water, (between $0.01 to $0.05 USD/$m^3$), is less than conventional treatment systems.
- They do not use chemical products. They are 100% automatic units, which are used when required, with response times of 10 to 60 s, at their efficiency level.
- EC technology is adaptable to different types of Wastewater Treatment Plants.

Electrocoagulation is applied to the mining industry, electroplating, refineries, and foundries, among others. **Table 3** shows the percentage of removal of main parameters. More information about EC Technology parameters can be found in Appendix 2.

Parameter	% of remotion
Molibden	83–87
Arsénic	95–98
Aluminum	> 99
Barium	> 98
Calcium	96–99
Cadmium	> 98
Cobalt	60–65
Crome	> 99
Cupper	> 99
Iron	> 99
Magnesium	98–99
Manganesum	83–85
Níquel	> 99
Selenium	> 99
Valadium	95–98
Zinc	> 99
Suspended solids (turbidity)	> 95
BOD	> 90
COD	> 90
Oils and fats	> 95
Total Nitrogen	> 80
Total Phosphorus	> 70
Fecal Coliforms*	> 99% (*)

**Using ozone, at the outlet of the electrocoagulation treatment plant, an outlet concentration of <50 MPN/100 ml of Total Coliforms will be reached.*

Table 3.
Percentage of removal of main parameters.

3.3 Cavitation as a depurative process in water treatment technology

The cavitation, electrolysis, and ozone system does not require adjuvants in the treatment of wastewater. Hydro cavitation is a recently used technique that has benefited from technological advances in wastewater treatment and is the subject of multiple investigations. Cavitation uses concepts related to the characterization of the formation, growth, and subsequent collapse of activities that generate large amounts of energy, creating hot spots and strong oxidation conditions through the production of hydroxyl radicals [19]. According to Foster [10], cavitation, a phenomenon defined as nucleation, involves the growth and implosion of cavities filled with steam or gas, which are achieved by the passage of ultrasound (acoustic cavitation) or by changes in flow and pressure (hydrodynamic cavitation). To develop hydrodynamic cavitation is necessary to modify the geometry of the flow to increase the kinetic energy. The cavitation increases by having a construction of the flow that results in a considerable reduction of the local pressure of the liquid. This change in the pressure of the liquid increases the kinetic energy. Drops in the liquid pressure below its vapor pressure create millions of vapor cavities, and turbulent conditions of varying pressure fields downstream of the construction occur. The lifetime of these cavities is very short (a few microseconds). The cavities finally violently implode and generate high pressures (up to 1000 bar) and very high temperatures (10,000°K). These changes intensify chemical reactions and promote the formation of radicals and their subsequent reactions [10]. Extreme shear forces generated by cavitation events and shock waves help break down contaminant molecules, especially the complex high molecular weight compounds. The intermediate compounds are more prone to hydroxyl radical attack and biological oxidation, further enhancing the overall rate of degradation and the mineralization of wastewater. Under such extreme conditions, the water molecule inside the cavity becomes OH and H radicals. The OH radicals diffuse into the liquid and react with contaminant molecules, resulting in oxidation and mineralization products [20]. Applications of this proven technology have been mentioned in cold water [21], municipal sewage [13, 15], industrial wastewater [17], reuse of winery wastewater, artisan production of wastewater reuse, and any waste that requires removal of organic contaminants (PHC/PAH, dioxin/PCB, pesticides), COD/BOD and reductions in TSS [14]. A prototype adapted by TRIO3, as shown in **Figure 13**, displays the cavitation technology. The schematic diagram proposed by the company, mentioning components in **Figure 14**, complies with the technical

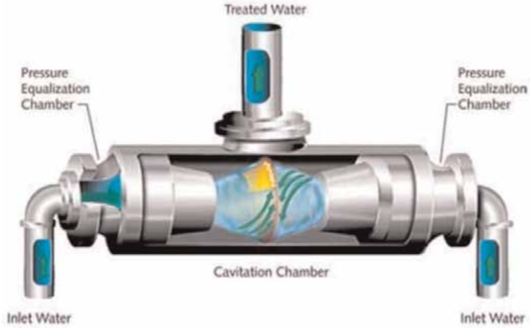


Figure 13.
Water treatment unit provided with cavitation technology (https://wcponline.com/2023/06/23).

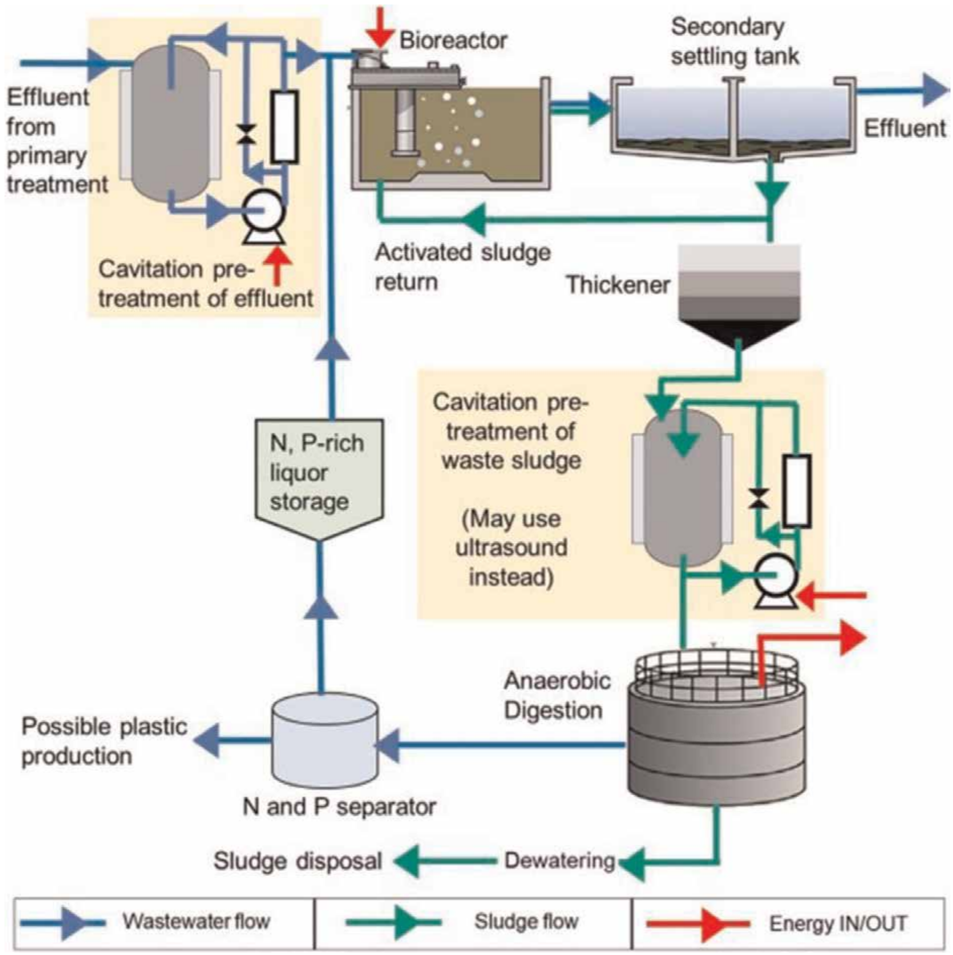


Figure 14.
Isometric diagram for a water treatment unit provided with cavitation technology. With permission of Bhat et al. (2021). https://www.sciencedirect.com/science/article/abs/pii.

Flow rate (l/s)	General dimensions		
	Length (m)	Width (m)	Height (m)
1.0–1.5	2.1	2.2	2.5
10	5	4	2.5
20	5	4	2.5
40	10	4	2.5
50	10	4	2.5

Table 4.
Specifications for the construction of hydro cavitation units.

specifications for water treatment procedures. According to the dimensions established in the equipment, the flow rate is dependent on these specifications as shown in **Table 4**.

The variables involved in **cavitation process** induce three common procedures but are different from each other [19]. These are: a) **electro-flotation,** where the gas to drag the contaminants previously conditioned to the surface is used, b) The **electrocoagulation-flotation** involves the injection of metal ions to agglutinate the pollutant agents dispersed in water, and directing them to the anode and sweeping the generated gas, and c) The **electrochemistry** operation involves redox reactions used to crack toxic compounds and treated later by biological procedures.

The process variables, above mentioned, relate to the type of contaminant to eliminate (see Appendix 2). Therefore, disinfection is due to anodic oxidation. Reingeniería en Saneamiento Ambiental Ltd. has made an effort to offer ecological Systems based on **Allotropic Physical Chemical Technology**. Through this ionization system, the molecules made up of two or more elements; dissociate the remaining molecules in their original state as atoms or ions. Thus, it softens the water, stabilizes the pH factor, and eliminates its encrusting capacity [7], as shown in **Figure 15**.

The urban wastewater treatment plant (WWTP) uses the process of technological innovation by electrolysis with photovoltaic energy and its construction process is with prefabricated PVC modules, which has the following advantages: quick installation by always having prefabricated parts in the warehouse, modular concept that allows future extensions, low cost of operation, low energy consumption, low sludge production, high system stability, easy operation, absence of unpleasant odors, and small area for installation. The dimensions of the proposed plant are based on the previously authorized final plans annexed to the WWTP contract and defining its scope. It is very important to note that, being a modular plant, the dimensions can be modified to adapt to the surface and geometry of the available land. The description of the proposed treatment process includes a plant with all the treatment units required to guarantee the correct purification of both wastewater and biological sludge, a product of the treatment process. The WWTP consists of a speed flocculation unit and an ionization unit. The treatment will be done in two phases; the first in a 15-min process of h**igh-speed flocculation** and the second in a 45-min phase of **high-impact ionization**, and final disinfection with ozone, with a capacity of 17.5 l/s for a period of 24 h, finally remaining for reuse. These are the main stages:

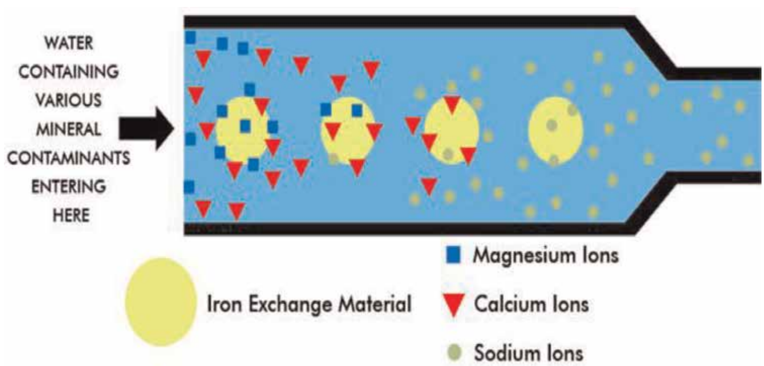


Figure 15.
Water deionization process. https://www.freedrinkingwater.com/water-education2/49-water-di-process.htm.

1. A screen is used for urban sewage to retain macro solids.

2. A regulator tank with a capacity of 45 m^3.

3. A sand trap with the capacity for the same flow.

4. High-speed flocculation unit. The system will be made up of 32 pieces of equipment, each consisting of four cathode electrodes 1¼" in diameter by 48″ length and two anode electrodes 1″ in diameter by 48″ length made of quality 316 stainless steel. Housed in eight tanks 1.50 m high by 1.00 m wide and 1.00 m length (1500 L each) made of hydraulic PVC schedule 40, with four equipment in each tank.

5. After the high-speed flocculation process, the water will pass to a hopper-type sedimentation tank, with a capacity of 14,000 L for separation of the sludge generated by this process and later passing to the sludge sump for disposal and the water to the system.

6. High-Impact Ionization Unit. The system will be made up of 96 pieces of equipment, each consisting of six cathode electrodes of 1¼" diameter by 48″ length and three anode electrodes of 3/4″ in diameter by 48″ long, made of quality 316 stainless steel. Housed in 24 tanks 1.50 m high by 1.00 m wide and 1.00 m long (1500 L each) made of hydraulic PVC schedule 40, depositing four teams in each.

7. Ozone Disinfection Reactor Tank Unit. The clarified and gauged water goes to the disinfection tank, which has a TriO3® brand Ozone system, in order to eliminate unwanted microorganisms and obtain treated water with the required quality. It has the function, as its name indicates, of disinfecting the water from pathogenic bacteria in humans, such as bacteria, viruses, and protozoa.

8. Sludge Digester. The excess sludge during the purification process is sent to the digester tank, where it is oxidized (a reduction of 40% of the volatile solids present in the sludge), since at this stage the microorganisms do not receive organic matter as food and they will only be provided with air (oxygen), promoting cannibalism (and at the same time avoiding the generation of odors) thus achieving a decrease in them, which will be ready for dehydration.

9. Sludge Drying Bed. The sludge previously stabilized in the digester and free of odors is sent to this equipment for drying, thus facilitating its handling and final disposal as a soil improver for green areas.

Because the WWTP proposed by TRIO3 is a modular type, the necessary modules can be increased according to the growth needs of the client. Following, **Figures 16** and **17** present a prototype of a WWTP using electroflocculation technology. **Figure 18** shows an oxidation lagoon and the disposal of treated water into the sea in the province of Santa Rosa Lambayeque, Peru.

Figure 16.
Picture of electroflocculation technology (copyright of Reingeniería en Saneamiento ltd).

4. Instruments and automation system in wastewater treatment process

In the last decades, the automation engineering of water treatment plants has presented advances that have led to improvements in the operation of the process [22]. For current plants, effective control is of critical importance, in terms of design, characteristics such as easy operation and maintenance and low operating cost are sought, as well as ensuring the capacity of the plant for the reduction or partial elimination of nutrients [23].

Due to the complexity of the treatment process, manual control of treatment plants may not provide the level of control necessary to meet all operating specifications. In this sense, in recent years with the rapid development of electronics, it is possible to use different devices such as Programmable Logic Controllers (PLCs), Industrial Computers, and Microcontrollers to carry out process control tasks automatically [24].

One of the most widely used control architectures for water treatment systems is SCADA (Supervisory Control and Data Acquisition) made up of different

Figure 17.
Picture of electroflocculation technology (copyright of Reingeniería en Saneamiento ltd).

Figure 18.
Oxidation lagoon and disposal of treated water in the district municipality of Santa Rosa Lambayeque, Peru (copyright of Reingeniería en Saneamiento ltd).

communication elements and human–machine interfaces, PLCs, remote terminals, and sensors. It is expected that this technology will soon be able to be adapted to the WTP technology to increase the productivity and automation of their processes. A human–machine interface (HMI) component is present within the SCADA tool, where human operators interact with the information acquired by the system through a browser interface, and also allows them to make decisions not programmed in the automatic system [25]. **Figure 19** illustrates the general architecture of an automated water treatment system.

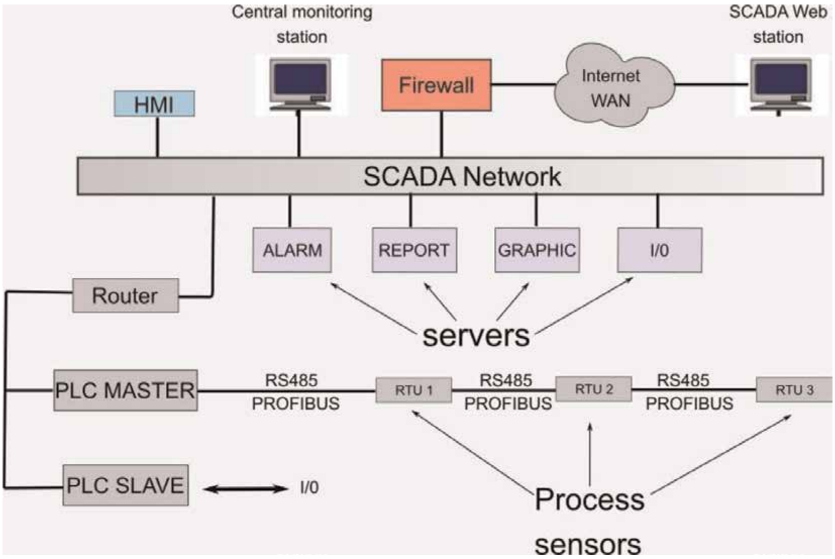


Figure 19.
SCADA hardware architecture for wastewater treatment plant. https://www.semanticscholar.org/paper/06/01/2023/Wastewater-treatment-plant-SCADA-application.

According to Wang [22], the following components can be considered as fundamental for the SCADA system:

- HMI (Human-Machine Interface). It presents human operators with the information acquired by the system through a browser interface, and also allows them to make decisions not programmed in the automatic system.
- Master unit of the SCADA system. It is in charge of acquiring the information collected by the remote stations and implementing the control law.
- RTUs (Remote Terminal Units). Automatically collects data and connects directly to process sensors. They function as slave units to the supervisory controllers or to the supervisory control and data acquisition (SCADA) master.
- PLC (Programmable Logic Controller). Used for automation of the wastewater treatment process and designed with multiple inputs and outputs. Its programming is in ladder language which is similar to electrical plans, which facilitates the interpretation of the code.

Additionally, the SCADA system has different sensors and transmitters which measure physical variables through different principles and convert them into physical signals for interpretation through the system. In general, PLCs are used in SCADA systems as process control elements, however, there are other alternatives such as Raspberry Pi boards, which can be more useful mainly for mobile treatment units (cavitation treatment) due to their size, energy consumption, and processing capacity [3, 26]. Raspberry Pi boards can be considered as microcomputers since they have a microprocessor that works under the ARM architecture and also has a series of digital I/O ports that allow acquiring the signal from the sensors and executing the control law through its Departures. The Raspberry pi must be accompanied by a power system to adjust the voltage and current levels of the board to those required by the process actuators [27].

5. Conclusions and discussion

There are several technologies in the market for WTP purposes. The electrocoagulation, cavitation, and ozone used separately for industrial purposes and municipal wastewater provides different removal efficiencies. This proposed chapter analyzes the benefits of using ozone for disinfection, deodoration, and adequate treatment of tap water, reuse, and recycling of wastewater. Preliminary studies developed by TRIO3 and Reingeniería en Saneamiento Ltd. demonstrate positive results using these technologies combined. The control of process variables in WWTP mentioned above involves novelty advances in ozone technology. Effective procedures discussed for the optimization of processes require more collaborative research in the usage of ozone.

Acknowledgements

Thanks to TECNM Campus Zacatecas Norte, TRIO3® Food Technologies and Reingeniería en Saneamiento Ambiental Ltd.

Nomenclature

PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls compounds
PHC	Petroleum hydrocarbon contamination

A. Appendix 1: A comparison of cavitation against other traditional techniques

Characteristics	Cavitation	Chemical	Biological	Reverse osmosis
Average cost per m^3 of treated water (Mex. Pesos)	7	12	15.0–30.0	30.0
Consumption of electrical energy per m^3 of treated water	4.5 kwh × m^3	4–6 kwh × m^3	12–15 kwh × m^3	3–12 kwh × m^3
Space required per m^3 of treated water		1	4	1
Process time per m^3 of treated water	22 min	1 h	23 h	30 min
Recycling and reuse of treated water	Partially	No	No	No
Possibility of expansion after entering into operation	Yes	No	No	No

Characteristics	Cavitation	Chemical	Biological	Reverse osmosis
Different water qualities using the same influent	Adaptable	No	No	No
Can treat residual wastewater?	Yes	Yes	Yes	No
Can obtain potable water?	Yes	No	No	Yes
A pretreatment before the process is required.	No	Yes	Yes	Yes
A residence time and stabilization stage are mandatory.	No	Yes	No	No
Modular expansion of the plant	Yes	No	No	No

B. Appendix 2: Contaminants concentration before and after use of electroflocculation technology including percentage of removal action (efficiency)

contaminant	Before (mg/L)	After (mg/L)	Total Removed (%)
Aldrin (pesticide)	0.063	0.001	98.4
Aluminum	224	0.69	99.69
Ammonia	49	19.4	60.41
Arsenic	0.076	<0.0022	97.12
Barium	0.0145	<0.0010	93.1
Benzene	90.1	0.359	99.6
BOD	1050	14	98.67
Boron	4.86	1.41	70.98
Cadmium	0.01252	<0.0040	96.81
Calcium	1321.00	21.4	98.4
Chlorieviphos (pesticide)	5.87	0.03	99.5
Chromium	1.39	<0.1000	99.92
Cobalt	0.1238	0.0214	82.71
Copper	0.7984	<0.0020	99.75
Cyanide (free)	723	<0.0200	99.99
Cypermethrin (pesticide)	1.3	0.07	94.6
DDT (pesticide)	0.261	0.002	99.2
Diazinon (pesticide)	34	0.21	99.4
Ethyl Berzene	428	0.372	99.91
Fluoride	1.1	0.415	62.27
Gold	5.72	1.38	75.87
Iron	68.34	0.1939	99.72
Lead	0.59	0.0032	99.46
Lindane (pesticide)	0.143	0.001	99.3
Magnesium	13.15	0.0444	99.66

contaminant	Before (mg/L)	After (mg/L)	Total Removed (%)
Magnanese	1.061	0.0184	98.27
Mercury	0.72	<0.0031	98.45
Molybdenum	0.35	0.029	91.71
MP-Xylene	41.6	0.057	99.86
MTBE	21.58	0.0462	99.79
Nickel	183	0.07	99.96
Nitrate	11.7	2.6	77.78
Nitrite	21	12	42.86
Nitrogen TKN	1118,88	59.08	94.72
NTU	35.38	0.32	99.1

Author details

Carlos Martín Enríquez Castro[1*], Manuel Pérez Nafarrate[2],
Anuar Manuel Badillo Olvera[3] and César Guzmán Martínez[4]

1 Food Engineering and Technology Program, TECNM Campus Zacatecas Norte, Río Grande, Zacatecas, México

2 TRIO3 Innovation Technologies and Reingeniería en Saneamiento Ambiental Ltd. Guadalajara, Jalisco, México

3 Electromechanical Engineering Program, TECNM Campus Zacatecas Norte, Río Grande, Zacatecas, México

4 Appalachian State University, Boone, NC, USA

*Address all correspondence to: carlos.ec@zacatecasnte.tecnm.mx

IntechOpen

© 2023 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Enríquez-Castro CM, Pérez-Nafarrate M, Gerardo Rodríguez JE. Innovation in food products using ozone technology: Impact on quality assurance. In: Innovation in the Food Sector through the Valorization of Food and Agro-Food by-Products. London, UK, London, UK: Intech Open; 2021

[2] Oner ME, Demirci A. Ozone for food decontamination: Theory and applications. Handbook of hygiene control in the food industry. 2016;491-501

[3] Kim J-G, Ahmed EY, Sandhya D. Application of ozone for enhancing the microbiological safety and quality of foods: A review. Journal of Food Protection. 1999;**62**(9):1071-1087

[4] Krstović S, Krulj J, Jaksic S, Bocarov-Stancic A, Jajic I, et al. Ozone as decontaminating agent for ground corn containing deoxynivalenol, zearalenone, and ochratoxin a. Cereal Chemistry. 2021;**98**(1):135-143

[5] Schirrmeister JF, Liebenow AL, Petz K, Wittmer A, Serr A, Hellwig E, et al. New bacterial compositions in root-filled teeth with periradicular lesions. Journal of Endodontics. 2009;**35**(2): 169-174

[6] Asfahl KL, Savin MC. Destruction of *Escherichia coli* and broad-host-range plasmid DNA in treated wastewater by dissolved ozone disinfection under laboratory and field conditions. Advances in Microbiology. 2012;**2**:1-7

[7] Wu Z, Shen H, Ondruschka B, Zhang Y, Wang W, Bremner DH. Removal of blue-green algae using the hybrid method of hydrodynamic cavitation and ozonation. Journal of Hazardous Materials. 2012;**235**:152-158

[8] Jain K, Patel AS, Pardhi VP, Flora SJS. Nanotechnology in wastewater management: A new paradigm towards wastewater treatment. Molecules. 2021; **26**(6):1797

[9] Nisar MA, Ross KE, Brown MH, Bentham R, Whiley H. *Legionella pneumophila* and protozoan hosts: Implications for the control of hospital and potable water systems. Pathogens. 2020;**9**(4):286

[10] Foster J, Sommers BS, Gucker SN, Blankson IM, Adamovski G. Perspectives on the interaction of plasmas with liquid water for water purification. IEEE Transactions on Plasma Science. 2012; **40**(5):1311-1323

[11] Asaithambi P, Govindararajan R, Yesuf MB, Selvakumar P, Alemayehu E, et al. Enhanced treatment of landfill leachate wastewater using sono (US)-ozone (O3)–electrocoagulation (EC) process: Role of process parameters on color, COD and electrical energy consumption. Process Safety and Environmental Protection. 2020;**142**: 212-218

[12] Östman M, Bjorlenius B, Fick J, Tysklind M. Effect of full-scale ozonation and pilot-scale granular activated carbon on the removal of biocides, antimycotics and antibiotics in a sewage treatment plant. Science of the Total Environment. 2019;**649**: 1117-1123

[13] Li W, Li C, Zhu N, Yuan H, Shen Y. The extent of sludge solubilization allows to estimate the efficacy of ozonation for removal of polycyclic aromatic hydrocarbons (PAHs) in municipal sewage sludge. Journal of Hazardous Materials. 2021;**413**:125404

[14] Wang J, Zhang X, Li G. Effects of ozonation on soil organic matter of contaminated soil containing residual oil. Journal of Soils and Sediments. 2012; **12**(2):117-127

[15] Ried A, Mielcke J, Wieland A. The potential use of ozone in municipal wastewater. Ozone: Science & Engineering. 2009;**31**(6):415-421

[16] Gogate PR, Mededovic-Thagard S, McGuire D, Chapas G, Blackmon J, Cathey R. Hybrid reactor based on combined cavitation and ozonation: From concept to practical reality. Ultrasonics Sonochemistry. 2014;**21**(2): 590-598

[17] Bilińska L, Blus K, Gmurek M, Ledakowicz S. Coupling of electrocoagulation and ozone treatment for textile wastewater reuse. Chemical Engineering Journal. 2019;**358**:992-1001

[18] Barrera-Díaz CE, Balderas-Hernández P, Bilyeu B. Electrocoagulation: Fundamentals and prospectives. In: Electrochemical water and wastewater treatment. 2018; 61-76

[19] Čehovin M et al. Hydrodynamic cavitation in combination with the ozone, hydrogen peroxide and the UV-based advanced oxidation processes for the removal of natural organic matter from drinking water. Ultrasonics Sonochemistry. 2017;**37**:394-404

[20] Bruggeman P, Schram DC. On OH production in water containing atmospheric pressure plasmas. Plasma Sources Science and Technology. 2010; **19**:045025

[21] Gardoni D, Vailati A, Canziani R. Decay of ozone in water: A review. Ozone: Science & Engineering. 2012; **34**(4):233-242

[22] Wang R, Jiaqi L, Xianbin GJ. Design and simulation of an ozone catalytic oxidation system based on programmable logic controller. Journal Européen des Systèmes Automatises. 2020;**53**:517-524

[23] Hong S-W, Choi Y, Kim SJ, Kwon G. Pilot-testing an alternative on-site wastewater treatment system for small communities and its automatic control. Water Science and Technology 2005;**51** (10):101-108

[24] Manesis SA, Sapidis DJ, King RE. Intelligent control of wastewater treatment plants. Artificial Intelligence in Engineering. 1998;**12**(3):275-281

[25] Humoreanu B, Nascu I. Wastewater treatment plant SCADA application. In: Proceedings of 2012 IEEE International Conference on Automation, Quality and Testing, Robotics. 2012:575-580

[26] Hamidi EAZ, Gustiana T, Effendi MR, Hambali PAM. Design and implementation supervisory control and data acquisition (SCADA) of flocculation process of water treatment plant (WTP) using raspberry pi. In: Proceeding of 2019 IEEE 5th International Conference on Wireless and Telematics (ICWT). 2019; 1-5

[27] Upadhyay D, Sampalli S. SCADA (supervisory control and data acquisition) systems: Vulnerability assessment and security recommendations. Computers & Security. 2020;**89**:101666

Chapter 3

Paraox Advanced Oxidation: An "Effective" Wastewater Treatment Process for Complex Organic Molecules Contamination

Thirumal Chandran, Mahesh Navnath Pharande and Shivangi Omer

Abstract

Mandatory in most part of the world to establish wastewater treatment plants before the treated effluent is discharged to any permittable discharge points. Wastewater treatment are based on the age-old concept of" activated sludge process" irrespective of the nature of effluent whether - "biodegradable, semi-biodegradable of non-biodegradable" resulting in untreated or partially treated effluent is being discharged in to receiving water. In this chapter we are discussing "Advanced Oxidation Processes (AOP)" in for various industrial segments after conducting pilot studies and full size industrial plant for various industrial segments such as leather, textile, chemical industries, engineering industries, automobile industries, fertilizer industry, petrochemical industries. Supplied industrial plants capable of not only provide proper treatment but also recover & recycle the treated effluent. In our "PARAOX" – we generate with our unique innovative patented AOP "ÖH" radicals & these "ÖH" radicals effecting mineralization of Complex Organic Molecules without generating. "sludge". We are enclosing relevant actual data conclude a systematic analysis of all existing scientific works which was carried out to verify the evolution of this line of research and representing its implication on industrial scale.

Keywords: advanced oxidation, sewage system, adsorption, hydroxyl radical, organic matter

1. Introduction

"Rapid Urbanizations" has resulted in more & more of "sophistication of Human Life". The "way of living" has changed so "dramatically in the past two decades, has resulted in more & more "man-made products" started entering in to a "Customer driven" market.

Most of the "consumer products" are made from many "different" synthetic chemicals" are ultimately discharged into the aquatic environment. Some of them are not only toxic but also partly biodegradable/non-biodegradable; therefore, they are not easily removed in biological wastewater treatment plants.

All most all the current treatment solutions for Complex Organic wastewater treatments leaves "residuals" that are toxic to receiving water and ultimately" pollute environment".

As all the natural water resources such as rivers & lakes off late is very badly affected due to these "residual non-bio gradable pollutants" – there is an urgent need explore more advanced alternative treatment methods to save our fragile environment.

2. Family of "complex organic compounds"

In a simple" organic compound" - A single carbon is bonded to just hydrogen. Complex organic compounds, especially those evolved in living systems, have more carbons bonded with hydrogen and oxygen.

Carbohydrates are molecules made of carbon, hydrogen, and oxygen. An example of a carbohydrate is table sugar, known as sucrose. Sucrose has the molecular formula $C_{12}\ H_{22}\ O_{11}$.

All complex organic molecules, like sucrose, are known as polymers. Polymers are complexes of repeated structural units. The structural units that make up polymers are called monomers [1, 2].

2.1 Paraox advanced oxidation process

PARAOX advanced Oxidation Process – the term "PARAOX" is an AOP based technology (INDIAN patent no. 380317) which were invented and implicated on an effective treatment process for the degradation of complex organic pollutants, "either to less harmful compounds open chain or to their complete mineralization to Carbon-di-oxide & water".

PARAOX advanced Oxidation Process, which involve the in-situ generation of highly potent chemical oxidants such as the hydroxyl radical (OH•), have recently emerged as an important class of technologies for accelerating the oxidation & destruction of a wide range of organic contaminants in polluted wastewater & air [3].

PARAOX advanced Oxidation Process - when applied on a right place, give a good opportunity to reduce the contaminant concentration from several hundred ppm to less than 5 ppb.

Because of this ability, PARAOX advanced Oxidation Process is known the treatment processes of the twenty-first century". Ït has the ability to even treat toxic & tough chemicals like "Nitro-phenols" (NPs) [4].

Nitro-phenols are used in manufacturing of varieties of pesticides, herbicides, insecticides, photochemical, wood preservatives and explosives. NPs may enter the environment from industrial discharges, spills, or possibly as a breakdown product of certain pesticides containing NPs (courtesy - EPA US, 1993) [1, 2, 4].

NPs have also been present in the degradation of pesticides like parathion and nitrofen. The generation of aqueous wastes during the formulation, distribution, and field application of pesticides is often unavoidable.

As secondary pollution arising from aromatic hydrocarbon & nitrogen oxide emissions by photochemical reactions in the atmosphere, NPs have been identified in cloud-and fog water condensates as well as on airborne particulate matter [5]. NPs are often detected in industrial effluents, in ambient freshwater, in marine environments, in the atmosphere and in soil.

NPs are very toxic compounds. They accumulate in the organism of "warm blooded". Towards animals and human, both the acute and chronic effects have been reported [6, 7]. Epidemiological studies of NPs have indicated that they damage central nervous system, liver, kidney and blood. They are highly toxic upon swallowing, inhalation and sorption through the skin [8].

2.2 Paraox advanced oxidation – A technology brief

1. State of the art decontamination technologies are based on "condensation, gas washing, adsorption, Bio-filtration, thermal, catalytic combustion, Electro-Coagulation or Electro Oxidation.

2. As a result, "pollution problems" are often only shifted from one medium to another because the pollutants are not decomposed to finally "CO_2 & H_2O"

3. Generic term "Advanced Oxidation Processes" leads to the 'decomposition & mineralization of many groups of organic materials present in both the liquid & gas phases [9].

4. Depending on the chemical structure of the pollutant molecules, in advanced Oxidation process mineralize numerous pollutants into ultimately harmless substances like CO_2 & H_2O and therefore "avoid the issue of pollution shifting" [10].

5. Advanced oxidation processes in general are physicochemical procedures which promote "in situ generation of free hydroxyl radicals" as highly oxidative reagents for the decomposition of pollutants in water & air [11].

6. The unique importance of these technologies is in "destroying biologically non-degradable chemical structures, ozone-resistant substances such as organic pesticides & herbicides, aromatic structures, Organo-halogens & petroleum constituents in wastewaters.

7. These oxidation processes basically use three different oxidants: "ozone, hydrogen peroxide & oxygen" in many combinations, either combined with each. Whereas "Paraox Advanced Oxidation" is applied with "UV irradiation & Ultrasonic & or various kinds of catalysts homogeneously and heterogeneously" due to the generation of "increased amounts of "OH" radicals" leads to higher oxidation rates [12].

3. Technology

Advanced Oxidation Process involves the three stages of oxidation of Complex organic molecules [13]:

Stage No. 1:

Generation/Formation of "OH" radical.

Stage No. 2:

It oxidizes easily oxidizable organic molecules in to Carbon-di-oxide & water and also breaks open complex organic molecules in to simple straight chain compounds. In other words, converts non - biodegradable in to biodegradable.

Stage No 3:

If the oxidation is allowed to continue further, then it further oxidizes the simple straight chain compounds to “Carbon-di-oxidize & water” [12, 13].

3.1 Hydroxyl radicals

- The Hydroxyl Radical •OH, is the neutral form of the Hydroxide ion (OH–). Hydroxyl radicals are highly reactive and consequently short lived [14].

- Most notably hydroxyl radicals are produced from the decomposition of Hydro-Peroxides (HOOH), by the reaction of excited atomic oxygen with water/Waste water.

- The Hydroxyl Radical is often referred to as the Detergent of the Troposphere because it reacts with many pollutants for their removal [15].

- It also has an important role in eliminating some greenhouse gases like methane & ozone [15].

- The “hydroxyl radical” is often referred to as the “detergent” of the “troposphere” because it reacts with many pollutants, often acting as the first step to their removal [15].

- The “rate of reaction with the hydroxyl radical” often determines how long many pollutants last in the atmosphere, if they do not “undergo photolysis” or are rained out [16].

- For instance, methane, which reacts relatively slowly with hydroxyl radical, has an average lifetime of >5 years and many CFCs have lifetimes of 50+ years. Pollutants, such as larger hydrocarbons, can have very short average lifetimes of less than a few hours [17].

- The coupled reaction with various nano copolymers in the pretreatment will enhance the duration of adsorption equilibrium will effectively disintegrate the organic contaminant and will reduce COD [18].

- Guargum, alginate, chitosan are the polymers grafted into activated carbon, nanogel, nanocomposites forms help in great extent to reduced volatile compounds by adsorption phenomena [19–21].

3.2 Science of producing hydroxyl radicals

We generate (OH) radical using the action of oxidants ozone, hydrogen peroxide, and ultraviolet radiation & ultrasound as per the following [22]:

1. Action of UV radiation on Hydrogen Peroxide: H_2O_2 + Light Energy from UV = 2 *OH

2. Action of UV Radiation on Ozone Gas: O_3 + Light Energy + H_2O_2 = H_2O_2 + O_2
   H_2O_2 + UV Energy – 2 *OH

3. Interaction Between Ozone & Hydrogen Peroxide: $2O_3$ + H_2O_2 = 2 *OH + 3 O_2

4. Generation of OH radical using cavitation process using Ultrasound.

3.3 Brief description – paraox advanced oxidation reactor: working/operating paraox reactor for treating complex effluent

1. Waste water (effluent) from any source can be treated using "Paraox Advanced Oxidation Reactor" & this reactor is working on the principles of "Advanced Oxidation" (**Figure 1**).

2. Raw effluent, if it is having suspended is filtered using conventional sand/bag/cartridge filtration process,

3. After eliminating suspended solids, it is then sent to a "Paraox Advanced Oxidation Reactor" (**Figure 2**).

4. Paraox Advanced Oxidation reactor is coupled with (**Figure 3**):

    a. Ozone Generator.

    b. Oxygen Concentrator.

    c. UV reactor using 254 nm wave length lamps.

    d. Dosing pumps to dose oxidants such as Hydrogen Peroxide, Hypo-chlorite.

    e. Ultrasonic transducers.

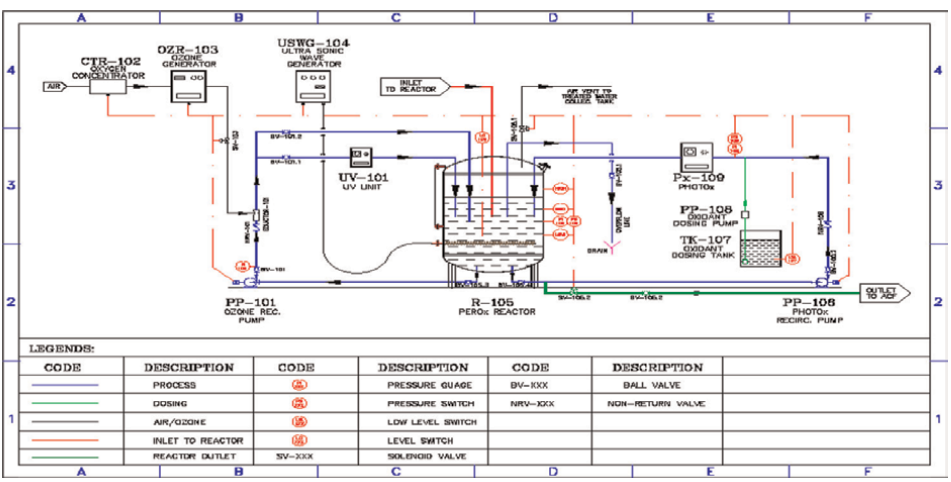


Figure 1.
Schematic flow representation of Paraox reactor.

Figure 2.
Image of Paraox reactor.

5. All these oxidants combined effectively generate "OH" radicals & the raw effluent is allowed to mix with the "OH" radicals to enable Oxidation process and convert the pollutants in to "Carbon-di-Oxide & Water" [23].

6. The 'Paraox Advanced Oxidation Reactor" is acting like a "OH radical Storage bank" where these "Oxidants either independently or combing with other oxidants keep on generating "OH" Radical since these oxidants are complementary to each other.

7. The generated "OH" radicals are allowed to thoroughly mix with the pollutants of the incoming effluent & it instantaneously oxidized to Carbon-di-oxide and water.

8. Depending up on the level of contamination, the number of stages of "Paraox Advanced Oxidation Reactors will be employed.

9. After the Paraox advanced oxidation reactor, the treated effluent is passed through a "Activated Carbon Filter" to absorb the excess oxidants in case it is present.

Figure 3.
Images of pilot plant used for technology validation.

3.4 Technology advantages

This is the Futuristic, Effective & Advanced Physio-Chemical Process. This is a Physio-Chemical Process targeting to treat feed from any Water & Waste Water for pollutants such as:

I. Chemical Oxygen demand/Biological oxygen Demand/Microbial Contaminations such as *E. Coli*, Pseudonymous etc.

II. Organic & in-Organic Iron content from deep bore wells & other deep wells.

III. Suspended Solids/Pesticides/Organic/Inorganic Color/Obnoxious Smell/ Volatile Organic Carbons such as Ethyl/Methyl Mercaptans.

IV. The wastewater when treated through our process brings in following advantages:

- The Dissolved Oxygen in the Treated Condensate will be a Minimum of 10.0 mg/l and up to 20.0 mg/l.
- No obnoxius smell & clear recovered treated wastewater will be available for reuse.

- Continuous running is not mandatory unlike biological process & can be easily and effectively run even at 30% of feed flow.

- Eliminates the requirement of Territory Treatment & the treated effluent will confirm to C.P.C.B standards & technology approved by Ministry of Environment & Forest.

- Disinfected & Microbial contamination confirming to drinking water standards of less than 100cfl & this will ensure that the Labor who comes in contact with the treated effluent will be safe.

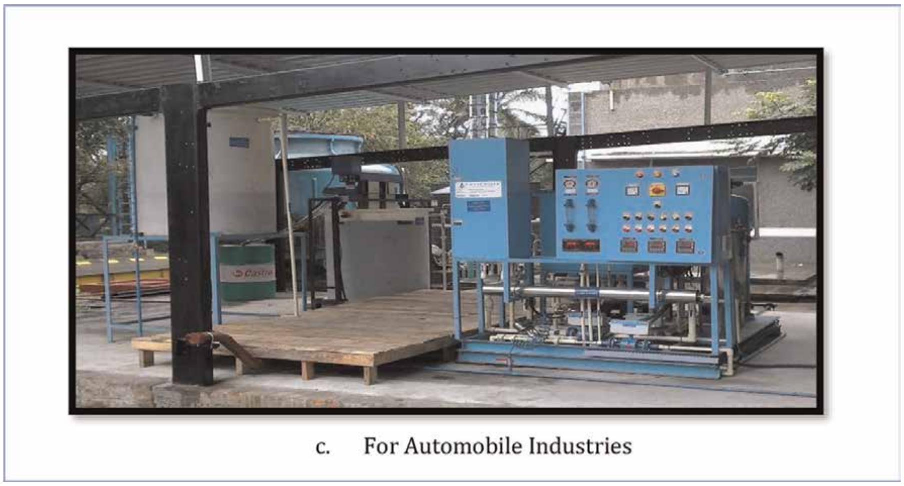
- Occupies lesser space compared to Conventional Biological Process & this process can be installed as Pre-Treatment, Post Treatment, Polishing treatment or Standalone treatment & can be installed at Ground Level, Basements or even at Elevated structures (**Table 1**).

a. For Biotech Industries

a. For Biotech Industries

b. For Pharma Industries

b. For Pharma Industries



c. For Automobile Industries

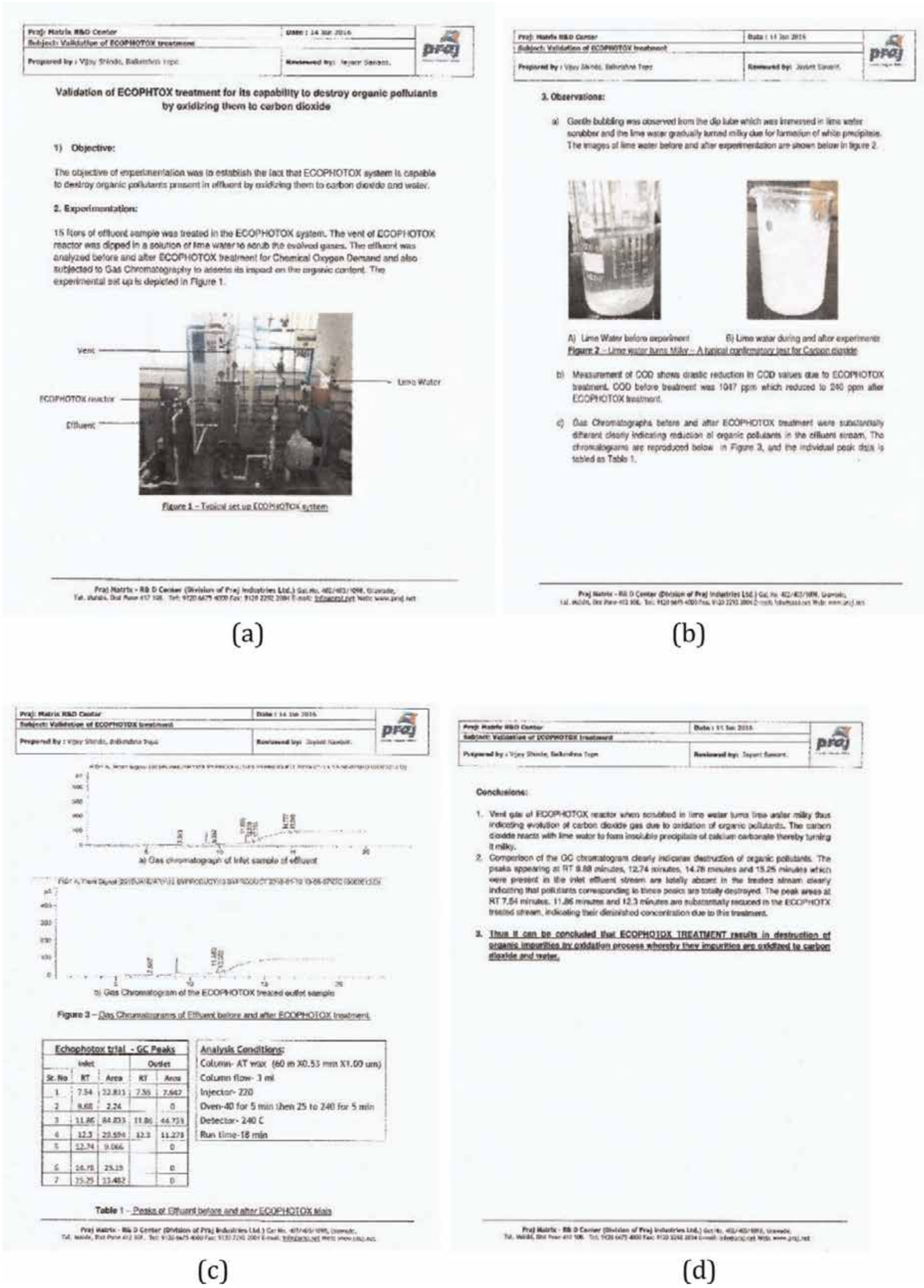
Table 1.
Image of plants for various industries (a). Biotech industries, (b). For pharma industries, (c). For automobile industries.

- Occupies lesser space compared to Conventional Biological Process & this process can be installed as Pre-Treatment, Post Treatment, Polishing treatment or Standalone treatment & can be installed at Ground Level, Basements or even at Elevated structures.
- Can treat Chemical/Biological Oxygen demand up to 40,000 ppm.
- Capacity augmentation is simple.
- Can run in Batch or Continuous mode.
- Can be used to increase the existing treatment plant capacities.
- Can be ideal treatment option for distilleries, Sugar, textile, Pharmaceutical, Pulp & Paper, Automobile/Engineering, Chemical Industries, Pesticides, Food & Beverages etc.

4. Paraox advanced oxidation process - validations trials

4.1 Paraox effluent recovery & recycling for textile industries alkali stream

(see **Figure 4 a-d**).
Seeing is believing: pilot trials on live samples:



Praj Matrix R&D Center | Date : 14 Jan 2016
Subject: Validation of ECOPHOTOX treatment
Prepared by : Vijay Shinde, Balkrishna Tope | Reviewed by: Jayant Sawant

Validation of ECOPHTOX treatment for its capability to destroy organic pollutants by oxidizing them to carbon dioxide

1) Objective:

The objective of experimentation was to establish the fact that ECOPHOTOX system is capable to destroy organic pollutants present in effluent by oxidizing them to carbon dioxide and water.

2. Experimentation:

15 liters of effluent sample was treated in the ECOPHOTOX system. The vent of ECOPHOTOX reactor was dipped in a solution of lime water to scrub the evolved gases. The effluent was analyzed before and after ECOPHOTOX treatment for Chemical Oxygen Demand and also subjected to Gas Chromatography to assess its impact on the organic content. The experimental set up is depicted in Figure 1.

Figure 1 – Typical set up ECOPHOTOX system

Praj Matrix - R& D Center (Division of Praj Industries Ltd.)

(a)

Praj Matrix R&D Center | Date : 14 Jan 2016
Subject: Validation of ECOPHOTOX treatment
Prepared by : Vijay Shinde, Balkrishna Tope | Reviewed by: Jayant Sawant

3. Observations:

a) Gentle bubbling was observed from the dip tube which was immersed in lime water scrubber and the lime water gradually turned milky due for formation of white precipitate. The images of lime water before and after experimentation are shown below in figure 2.

A) Lime Water before experiment B) Lime water during and after experiments

Figure 2 – Lime water turns Milky – A typical confirmatory test for Carbon dioxide

b) Measurement of COD shows drastic reduction in COD values due to ECOPHOTOX treatment. COD before treatment was 1047 ppm which reduced to 240 ppm after ECOPHOTOX treatment.

c) Gas Chromatographs before and after ECOPHOTOX treatment were substantially different clearly indicating reduction of organic pollutants in the effluent stream. The chromatograms are reproduced below in Figure 3, and the individual peak data is tabled as Table 1.

Praj Matrix - R& D Center (Division of Praj Industries Ltd.)

(b)

Praj Matrix R&D Center | Date : 14 Jan 2016
Subject: Validation of ECOPHOTOX treatment
Prepared by : Vijay Shinde, Balkrishna Tope | Reviewed by: Jayant Sawant

a) Gas chromatograph of inlet sample of effluent

b) Gas Chromatogram of the ECOPHOTOX treated outlet sample

Figure 3 – Gas Chromatograms of Effluent before and after ECOPHOTOX treatment

Echophotox trial - GC Peaks				
	Inlet		Outlet	
Sr. No	RT	Area	RT	Area
1	7.54	32.811	7.55	7.647
2	9.68	2.24		0
3	11.86	84.833	11.86	44.733
4	12.3	20.594	12.3	11.273
5	12.74	9.066		0
6	14.78	25.15		0
7	15.25	13.482		0

Analysis Conditions:
Column- AT wax (60 m X0.53 mm X1.00 um)
Column flow- 3 ml
Injector- 220
Oven-40 for 5 min then 25 to 240 for 5 min
Detector- 240 C
Run time-18 min

Table 1 – Peaks of Effluent before and after ECOPHOTOX trials

Praj Matrix - R& D Center (Division of Praj Industries Ltd.)

(c)

Praj Matrix R&D Center | Date : 14 Jan 2016
Subject: Validation of ECOPHOTOX treatment
Prepared by : Vijay Shinde, Balkrishna Tope | Reviewed by: Jayant Sawant

Conclusions:

1. Vent gas of ECOPHOTOX reactor when scrubbed in lime water turns lime water milky thus indicating evolution of carbon dioxide gas due to oxidation of organic pollutants. The carbon dioxide reacts with lime water to form insoluble precipitate of calcium carbonate thereby turning it milky.
2. Comparison of the GC chromatogram clearly indicates destruction of organic pollutants. The peaks appearing at RT 9.88 minutes, 12.74 minutes, 14.78 minutes and 15.25 minutes which were present in the inlet effluent stream are totally absent in the treated stream clearly indicating that pollutants corresponding to these peaks are totally destroyed. The peak areas at RT 7.54 minutes, 11.86 minutes and 12.3 minutes are substantially reduced in the ECOPHOTX treated stream, indicating their diminished concentration due to this treatment.
3. **Thus it can be concluded that ECOPHOTOX TREATMENT results in destruction of organic impurities by oxidation process whereby they impurities are oxidized to carbon dioxide and water.**

Praj Matrix - R& D Center (Division of Praj Industries Ltd.)

(d)

Figure 4.
(a-d) Images of acknowledgement for process validation.

4.1.1 Raw effluent evaluation report (alkaline effluent)

Please refer **Table 2(a)** and **(b).**

4.1.2 Paraox effluent recovery & recycling for textile industries (acid stream)

Please refer **Table 3(a)** and **(b).**

a. Raw effluent parameters

Parameters	**Value**
Total dissolved solids by meter	4050 ppm
Chemical oxygen demand	10,240 ppm
pH	11.2
Smell	Strong & pungent
Appearance	Turbid
Color	Yellow

b. Treated effluent parameters.

Total dissolved solids by meter	3310.0 ppm
Chemical oxygen demand	2020.0 ppm
pH	8.7
Smell	Very slight
Appearance	Clear
Color	Color less
Oxidant	Hydrogen peroxide

Table 2.
(a, b) Raw effluent evaluation report: Alkaline effluent (Raw and treated effluent parameters).

a. Raw effluent parameters

Parameters	**Value**
pH	3.1
T.D.S	2320 ppm.
Appearance	Turbid.
Color	Bluish black
C.O.D	1450 ppm
T.S.S	2050 ppm
Hardness	510 ppm

a. Raw effluent parameters	
Parameters	**Value**
b. Treated effluent parameters.	
pH	4.1
T.D.S	5120 ppm
Appearance	Clear
Color	Light yellow tint.
C.O.D % reduction	340 ppm. (90.6%)
T.S.S	<10 ppm
Hardness	600 ppm

Table 3.
(a, b)Raw & treated effluent evaluation report: Acid effluent (Raw and treated effluent parameters).

4.1.3 Paraox effluent recovery - distillery condensate

Please refer **Table 4**.

4.1.4 Paraox effluent recovery - spray pond inlet effluent

Please refer **Table 5**.

Date	**Details.**		**pH**	**Conductivity**	**T.D.S**	**C.O.D**	**% Red. C.O.D.**
09.02.22	Before purifications		9.16	6200	4030	5000	—
09.02.22	After purify -cation	01	8.95	7200	4320	228	95.44
		02	8.88	7000	4550	180	96.44
		03	8.80	7600	4940	196	96.08
		04	8.375	7400	4810	250	95.00
		05	8.66	7500	4875	320	93.60

Table 4.
Trial reports: Distillery condensate (before and after purification).

Date	**Details.**		**pH**	**Conductivity**	**T.D.S**	**C.O.D**	
07.02.22	Before purifications		5.70	1500	975	4000	—
07.02.22	After purification	01	5.00	1850	1202	800	80.00
		02	4.90	1220	1222	200	95.00
		03	4.90	1870	1216	100	97.50

Table 5.
Trial reports: Trial reports: Spray pond inlet water: (before and after purification).

सिताराम महाराज
साखर कारखाना (खर्डी) लि.,
मु.पो.खर्डी, ता.पंढरपूर, जि.सोलापूर. 413317(MH)
email : gm.sitaramsugar@gmail.com

R.No.U15424 PN 1999 PLCO 13656 | ९४२१८७६३५२ | GST.No.:- 27AAOCS0492B1ZC

E.T.P. Erection and Commissioning Report

(Capacity-960 KL/Day)

Date: - 09/01/2023

Client Name : - SITARAM MAHARAJ SAKHAR KARKHANA, Khardi.

Project Code : - P-105

PO No. :- ADAXY/SUGAR CPU/SITARAM /026.

Site Address : - Khardi, Tal- Pandharpur, Dist. – Solapur. .
Pin code-413317

Commissioning Date: - 06/01/2023 – 09/01/2023

This is to certify that **M/s Adaxy Tech Pvt Ltd.,** having their corporate office at 401-404, Wing A, Pawan Appt, Pashan, Pune-411057 (India) has successfully designed, engineered and erected " "CONDENSATE RECOVERY & RECYCLING PLANT, Based On "PARROX ADVANCE OXIDATION PROCESS" of Capacity **960 KLD per day at SITARAM MAHARAJ SAKHAR KARKHANA. Khardi, Tal- Pandharpur, Dist. – Solapur.** as per above referred Purchase Order.

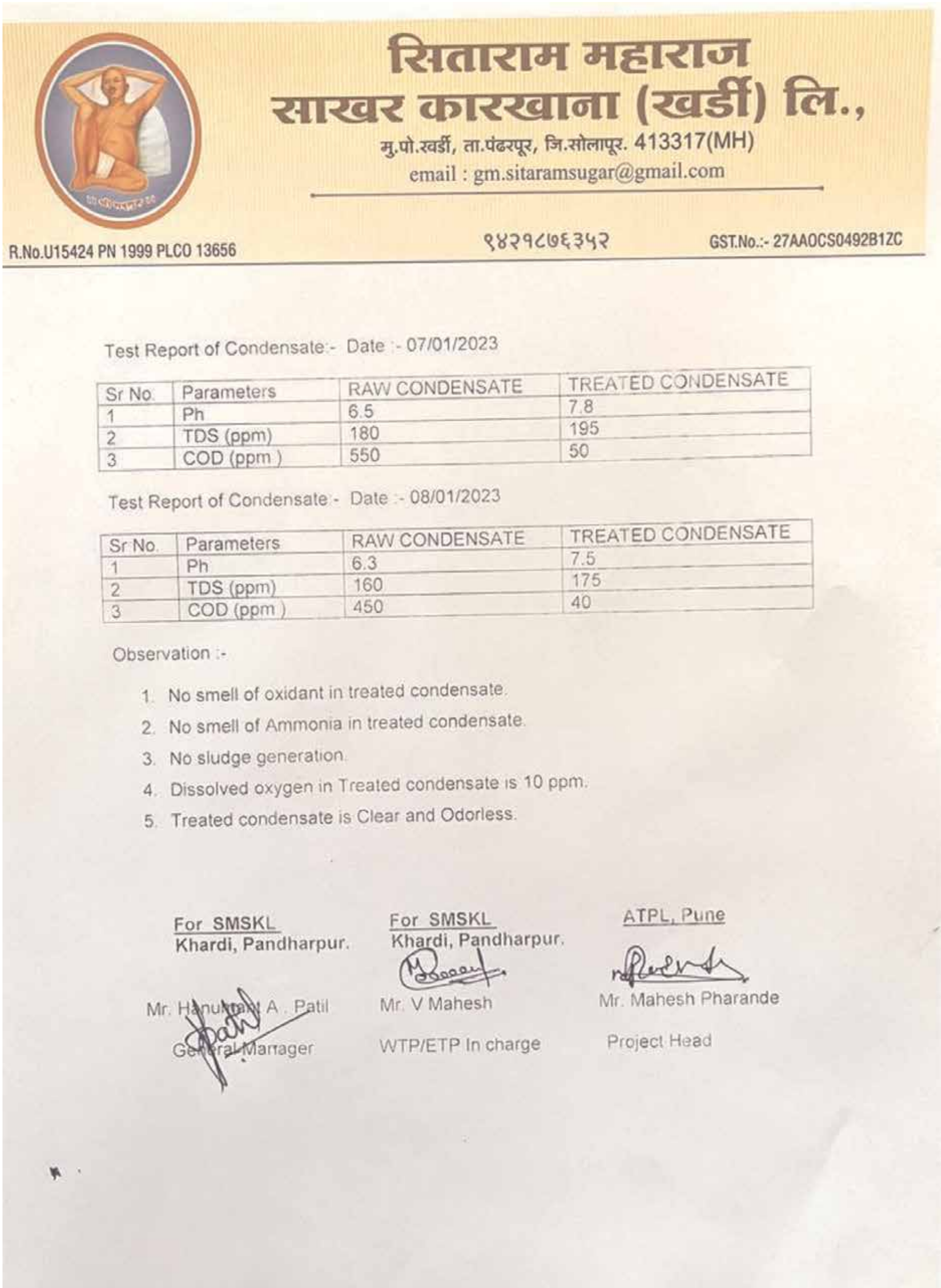
The Commissioning trials of the plant were started on 6 th Jan 2023. Treated Condensate sample was collected on 7 th,8 th Jan by M/s Adaxy tech Pvt Ltd in presence of SMSKL Operator and plant head , Analysis done at site in SMSKL lab .

The Analysis report of the sample is attached herewith the commissioning letter. All parameters of the Treated condensate are within the range mentioned in the "Design Specifications'.

M/s. Adaxy Tech Pvt Ltd now is pleased to hand over the Plant to M/s. SMSKL.

For SMSKL Khardi, Pandharpur.	For SMSKL Khardi, Pandharpur.	ATPL, Pune
Mr. Hanumant A . Patil	Mr. V Mahesh	Mr. Mahesh Pharande
General Manager	WTP/ETP In charge	Project Head

(a)



सिताराम महाराज
साखर कारखाना (खर्डी) लि.,
मु.पो.खर्डी, ता.पंढरपूर, जि.सोलापूर. 413317(MH)
email : gm.sitaramsugar@gmail.com

R.No.U15424 PN 1999 PLCO 13656 ९४२१८७६३५२ GST.No.:- 27AAOCS0492B1ZC

Test Report of Condensate:- Date :- 07/01/2023

Sr No	Parameters	RAW CONDENSATE	TREATED CONDENSATE
1	Ph	6.5	7.8
2	TDS (ppm)	180	195
3	COD (ppm)	550	50

Test Report of Condensate:- Date :- 08/01/2023

Sr No.	Parameters	RAW CONDENSATE	TREATED CONDENSATE
1	Ph	6.3	7.5
2	TDS (ppm)	160	175
3	COD (ppm)	450	40

Observation :-

1. No smell of oxidant in treated condensate.
2. No smell of Ammonia in treated condensate.
3. No sludge generation.
4. Dissolved oxygen in Treated condensate is 10 ppm.
5. Treated condensate is Clear and Odorless.

For SMSKL
Khardi, Pandharpur.
Mr. Hanumant A . Patil
General Manager

For SMSKL
Khardi, Pandharpur.
Mr. V Mahesh
WTP/ETP In charge

ATPL, Pune
Mr. Mahesh Pharande
Project Head

(b)

Figure 5.
(a,b) Commissioning & handing over report for "paraox advanced condensate recovery and recycling plant of capacity – 950.0 m^3*/day.*

Observations during the trials:

1. No smell of Oxidants observed during the trial.

2. No smell Ozone smell is observed.

3. No "sludge generation" seen in spite of C.O.D reduction over 96.0% - The effluent remained clear without any suspended solids.

4. Neat & Clean operation.

5. Compact & very less area occupied for the capacity.

6. Treated effluent Dissolved Oxygen is maintained above 12.00 ppm.

7. Treated effluent is Clear & Colorless (**Figure 5a,b**).

4.1.5 Paraox effluent recovery - neem oil industry

Please refer **Table 6(a** and **b)**.

a. Raw effluent parameter:	
Sample identification	1 from the 200 liters drum
Reduction after Coagulation & Filtration	14.70%
pH	5.7
T.D.S. (By HENA hand held meter)	2830 ppm.
C.O.D before filtration	30,500 ppm
C.O.D after pre-treatment	26,500 ppm
Color	Dark brownish
Smell	Intense very foul smell of degradation.
Actual photographs	
Dissolved Oxygen	Less than 0.5 ppm
O.R.P	−240

a. Raw effluent parameter:	
b. Treated effluent characteristics:	
pH	5.1
T.D.S. (By HENA hand held meter)	3300 ppm
C.O.D after treatment	6710 ppm
% Reduction	78%
Color	Very pale yellow (Almost Color less).
Smell	Mild foul smell (Smell of degradation)
Actual Photographs	
Dissolved Oxygen	Around 12.8 ppm
O.R. P	+249
Change in ORP	From −240 to +249

Table 6.
Paraox effluent recovery - Neem oil industry (a). Raw effluent, (b). treated water parameters.

4.1.6 Paraox effluent recovery - textile effluent: Salt recover & recycling

Please refer **Table 7(a-c)**.

4.1.7 Spent coolant recovery & recycling (patent No. ___________)

Please refer **Table 8(a** and **b)**.

5. Conclusion

Along with other advantages, Paraox Advanced Oxidation Process is truly a "Futuristic" &" Eco-friendly" process:

1. In the current scenario of Atmospheric Oxygen depleted condition due to industrialization, the Paraox Advanced Oxidation plants induces "dissolved oxygen "in the atmosphere. The treated effluent using Paraox Advanced Oxidation" can be maintained between 10.0 20.0 mg/l.

2. Will benefit plants & aquatic life.

DOI: http://dx.doi.org/10.5772/intechopen.111390

a. Raw Solution characteristics:	
Sample identification	Mixed salt bag sent by Mr. Sudhakar.
Sample Preparation	6.0 kg of mixed salt is taken for trial & diluted in 35 liters of Corporation water having TDS of 120 ppm
pH	1.0
T.D.S. (By HENA hand held meter)	14,500 ppm
C.O.D (raw)	880 ppm
Color	Dark brownish
Actual photographs	
Dissolved Oxygen	Less than 0.5 ppm
O.R. P	−240

b. Treated solution characteristics:	
pH	1.0
T.D.S. (By HENA handheld meter)	12,300 ppm.
C.O.D after treatment	60 ppm
% Reduction	93.2%
Color	Almost colorless
Smell	Milt oxidizing chemical smell
Dissolved oxygen	Around 14.0 ppm
O.R.P	+249
Change in ORP	From −240 to +400
Actual photographs	

DOI: http://dx.doi.org/10.5772/intechopen.111390

c. Recovered salt:	
pH	—
Mother liquor solution	20 gram in 2 liters
 Evaporator salt	 Recycled salt

Table 7.
(a). Raw prepared salt solution, (b). Treated prepared salt solution, (c). Recovered salt.

a. Spent Coolant Collected from Menon Pisto.	
Sample identification	Green color carboy of 35.0 liters capacity
Sample volume taken for trial	30 liters.
pH	8.4
T.D.S. (By HENA TDS meter)	2300 ppm
Color	Dirty gray with layer of oil on surface
Dissolved Oxygen	Not detected
Refractive Index	Less than 0.3
Flow Through Capillary (Compared with water): Water @ room temp. Raw Waste Coolant at room temperature.	1.29 seconds. 1.33 seconds.
ORP Values	(−)340
Smell	Heavy rotten egg & pungent smell.
Raw Waste Coolant	 

DOI: http://dx.doi.org/10.5772/intechopen.111390

Recovered dilution water & recovered metal scrap.	 
Bacta Slide. (Total Bacterial Count in Raw Waste Coolant) is more than 107.	

b. Treated coolant (recovered coolant):	
Sample identification	Green color carboy of 35.0 liters capacity
Sample volume taken for trial	30 liters
pH	8.0
T.D.S. (By HENA TDS meter)	1400 ppm
Color	Milky White.
ORP	(+)190
Smell	Fresh coolant smell
Dissolved Oxygen	24 ppm
Bacta slide reading	TBC population not detected
Recovered Coolant with Refractive Index of 2.20. (Refractive index of the fresh coolant in the factory as per the customer is 2.0%)	8 liters. (Around 27%)
Recovered Permeate through UF membrane	22 liters.

DOI: http://dx.doi.org/10.5772/intechopen.111390

Bacta Slide. (Total Bacterial Count in Raw Waste Coolant) is not detected.	

Table 8.
Spent coolant recovery & recycling technology (a). Spent coolant collected from Menon Pisto, (b). Treated coolant (recovered coolant).

3. Paraox Advanced Oxidation do not convert "one form of pollution in to another" – it's a "no sludge process". Whatever suspended solids present in the raw effluent is only separated as "sludge".

4. The "complex organic molecules are at the end of the oxidation process" is converted in the "Corban-di-oxide & water – an ultimate natural element.

5. "Traces or nil" oxidation by-products"- safe for soil & inland irrigation.

6. Very effective for "ammoniacal nitrogen treatment – will benefit the sewage treatment plants.

7. Can be a "solution" for "leachate treatment".

8. Can convert "non-biodegradable"" in to "biodegradable".

9. Can be a "stand alone" treatment or "can be plugged" in before or after the existing treatment facilities to improve treatability.

10. In short "PARAOX advanced Oxidation Process is known as the treatment processes of the twenty-first century".

Author details

Thirumal Chandran[1*], Mahesh Navnath Pharande[1] and Shivangi Omer[2]

1 C.M.D Wytewater Technologies Pvt. Ltd., India

2 Adaxytech. Pvt. Ltd, Pune, India

*Address all correspondence to: thchandren@yahoo.com

IntechOpen

© 2023 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Garrido-Cardenas JA, Esteban-García B, Agüera A, Sánchez-Pérez JA, Manzano-Agugliaro F. Wastewater treatment by advanced oxidation process and their worldwide research trends. International Journal of Environmental Research and Public Health. 2020;**17**(1):170

[2] Omer S. Heavy metal removal by alginate based agriculture, and industrial waste nanocomposites. In: Deniz I, Imamoglu E, Keskin-Gundogdu T, editors. Properties and Applications of Alginates. London, UK, London, UK: IntechOpen; 2021. DOI: 10.5772/intechopen.98832

[3] Mandal T, Maity S, Dasgupta D, Datta S. Advanced oxidation process and biotreatment: Their roles in combined industrial wastewater treatment. Desalination. 2010;**250**(1):87-94

[4] Saritha P, Aparna C, Himabindu V, Anjaneyulu YJJOHM. Comparison of various advanced oxidation processes for the degradation of 4-chloro-2 nitrophenol. Journal of Hazardous Materials. 2007;**149**(3):609-614

[5] Herterich R. Gas chromatographic determination of nitrophenols in atmospheric liquid water and airborne particulates. Journal of Chromatography A. 1991;**549**:313-324

[6] Trapido M, Kallas J. Advanced oxidation processes for the degradation and detoxification of 4-nitrophenol. Environmental Technology. 2000;**21**(7):799-808

[7] Zou JP, Chen Y, Liu SS, Xing QJ, Dong WH, Luo XB, et al. Electrochemical oxidation and advanced oxidation processes using a 3D hexagonal Co3O4 array anode for 4-nitrophenol decomposition coupled with simultaneous CO2 conversion to liquid fuels via a flower-like CuO cathode. Water Research. 2019;**150**:330-339

[8] Mi Y, Zhang C, Li CM, Taneda S, Watanabe G, Suzuki AK, et al. Protective effect of quercetin on the reproductive toxicity of 4-nitrophenol in diesel exhaust particles on male embryonic chickens. Journal of Reproduction and Development. 2010;**56**(2):195-199

[9] Rivas J, Encinas Á, Beltrán F, Graham N. Application of advanced oxidation processes to doxycycline and norfloxacin removal from water. Journal of Environmental Science and Health, Part A. 2011;**46**(9):944-951

[10] Gągol M, Cako E, Fedorov K, Soltani RDC, Przyjazny A, Boczkaj G. Hydrodynamic cavitation based advanced oxidation processes: Studies on specific effects of inorganic acids on the degradation effectiveness of organic pollutants. Journal of Molecular Liquids. 2020;**307**:113002

[11] Mehrjouei M. Advanced oxidation processes for water treatment: Reactor design and case studies. BTU Cottbus-Senftenberg. 2012 (Doctoral dissertation)

[12] Elmobarak WF, Hameed BH, Almomani F, Abdullah AZ. A review on the treatment of petroleum refinery wastewater using advanced oxidation processes. Catalysts. 2021;**11**(7):782

[13] Vilhunen S, Sillanpää M. Recent developments in photochemical and chemical AOPs in water treatment: A mini review. Reviews in Environmental Science and Bio/Technology. 2010;**9**(4):323-330

[14] Younes M. Free radicals and reactive oxygen species. In: Toxicology. Academic Press; 1999. pp. 111-125

[15] Li S, Matthews J, Sinha A. Atmospheric hydroxyl radical production from electronically excited NO_2 and H_2O. Science. 2008;**319**(5870): 1657-1660

[16] Anbar M, Meyerstein D, Neta PJTJC. The reactivity of aromatic compounds toward hydroxyl radicals. The Journal of Physical Chemistry. 1966;**70**(8):2660-2662

[17] Gierczak T, Talukdar RK, Herndon SC, Vaghjiani GL, Ravishankara AR. Rate coefficients for the reactions of hydroxyl radicals with methane and deuterated methanes. The Journal of Physical Chemistry A. 1997; **101**(17):3125-3134

[18] Singh A, Omer S. Adsorption of Heavy Metal Using Biomass Ash and Guar Gum Nanocomposite from Wastewater Effluent – A Review. Vol. 1. SSRN- Elsevier; 2018. p. 3

[19] Omer S, Singh A, Upadhyay S. Synthesis of chitosan-g-biomass ash/ graphene oxide nanocomposite for the removal of copper and chromium from industrial wastewater. Clay Research. 2019;**38**(1):19-28

[20] Omer S, Singh A, Sasmal R, Singhal A. Adsorption studies on chitosan and guar gum nanocomposite by application of agriculture waste–A review. International Journal of Research and Analytical Reviews. 2019;**6**: 1059-1062

[21] Omer S, Anand S, Singh SK, Singh A. Review study on waste Tire as an adsorbent to remove toxic metals from wastewater. International Journal of Pharmaceutical and Medicinal Research. 2020;**8**(1):1-5

[22] Mierzwa JC, Rodrigues R, Teixeira AC. UV-hydrogen peroxide processes. In: Advanced Oxidation Processes for Wastewater Treatment. Academic Press; 2018. pp. 13-48

[23] Schorr V, Boval B, Hancil V, Smith JM. Photooxidation kinetics of organic pollutants in municipal waste water. Industrial & Engineering Chemistry Process Design and Development. 1971;**10**(4):509-514

Chapter 4

Ozonation of Non-Woven Ultrathin Fibrous Biomaterials for Medical and Packaging Implementations

Olga Alexeeva, Valentina Siracusa, Marina L. Konstantinova, Anatoliy A. Olkhov, Alexey L. Iordanskii and Alexandr A. Berlin

Abstract

Antibiotic resistance of pathogens is among the major concerns in various medical applications. Therefore, the search for the novel antimicrobial agents that could prevent pathogen's resistance, while maintaining efficient treatment, is one of the most important issues for biomedicine nowadays. One of the relevant methods for the development of functional non-woven materials possessing antimicrobial properties is the use of ozone and ozonolysis products for the modification of fibrous materials. This approach has recently attracted both academic and industrial interest and has found various biomedical applications. Several methods providing antimicrobial properties to textiles using ozone or ozonolysis products were proposed, including encapsulation and/or direct introduction of ozone-generated antimicrobial agents into the fibrous polymer matrix and ozone treatment of non-woven fiber materials. For the latter, the ozonolysis products are uniformly distributed predominantly on the polymer surface but could be also formed inside the polymer bulk due to ozone diffusion through the amorphous areas or defects. It was found that ozone modification of fibrous materials could lead to increase in hydrophilicity and improvement in their functional properties (smoothness, elasticity, strength, antimicrobial activity). In this chapter, various aspects of ozone modification of non-woven fiber materials for biomedical applications are reported and discussed.

Keywords: ozone, non-woven, ultrathin, biomaterials, packaging, health

1. Introduction

Over the past decades, functional nonwoven materials, obtained by modern nanotechnological methods, have been intensively studied at the academic and industrial levels [1–3]. Commercially available, biodegradable polymers produced as ultrafine fibers are gaining more interest as a result of their high surface/volume ratio, biocompatibility, non-toxicity in the body, and environmental compatibility. Due to their thermoplasticity and the ability to form solutions with bioactive compounds, they can be directly introduced into biomedical or packaging materials to give them new functional properties, including antimicrobial ones [4–7].

The search for new antimicrobial substances that can simultaneously reduce the resistance of pathogens to antibiotics and maintain high therapeutic activity is one of the most important modern tasks of biomedicine and the packaging industry [8, 9]. The success of the use of bactericidal plastics [10] is based on the absence of the ability to cause allergic reactions and the possibility of implementing controlled biodegradation, as well as on improved mechanical and barrier characteristics that expand the scope of their application [11–13].

Currently, a number of studies are underway aimed at the use of antimicrobial agents in fibers and nonwovens in medicine. For example, lipid systems containing omega-3 fatty acids or omega-3 fatty acids and liposomes are incorporated into woven, non-woven cotton substrates by impregnation. Also, the use of fibrous materials with a drug already introduced into the biopolymer [14–17]: dipyridamole and tetraphenylporphyrins is being actively studied. Based on the evaluation of release profiles, textiles are expected to be useful for wound healing and anti-inflammatory applications.

Bactericidal materials providing an effective barrier and selective properties belong to the class of active packages. This is a modern trend in the development of innovative materials for the food, cosmetics, and agriculture industries, in addition to their active functions [18]. The bactericidal properties of barrier materials can be achieved by encapsulating antiseptics/antibiotics in a matrix or on the surface of the packaging material, which leads to the suppression of microbial growth by reducing the population of microorganisms and reducing their growth rate [19]. In this case, the period of active operation of the package and the storage time of the product increase significantly along with an increase in the safety of transportation.

The development and production of ultrathin biodegradable fibers by electrospinning made it possible to create new fibrillar materials, the intensive use of which is clearly observed in many interdisciplinary areas [20–22]. Electrospinning is a technically simple and at the same time universal method for obtaining ultrathin fibers in the micro- and nano-ranges of their diameters, which contributes to the widespread use of this nanotechnology for the design of structural and functional materials with innovative performance characteristics. Fibrillar nanosized materials have high porosity and large specific surface area, which allows them to be used as highly efficient filters and absorbents. In addition, electroformed polymeric materials can be successfully modified with various biologically active compounds, biomolecules, and carbon nanomaterials [23]. The introduced additives should have good compatibility with the polymer and be safe for use in biomedical and environmental issues [24].

The use of ozone and ozonolysis products for fibrous materials modification is one of the innovative approaches to the creation of functional micro- and nanomaterials with antimicrobial properties. Ozone, as an individual gaseous compound, is the strongest oxidizing agent and, therefore, a powerful disinfectant [25, 26]. Based on the analysis of the ozonolysis kinetics, it became possible to accurately dose its concentration and obtain ozonolysis products with the necessary disinfecting properties [27]. For example, when ozonizing vegetable oils, ozone reacts with unsaturated triacylglycerols contained in them (**Figure 2**) [28]. The oil ozonation product is a non-toxic, biocompatible, and biodegradable material, and is also a promising additive for introduction into the fibrillar matrix through electrospinning [29]. Combining the plasticizing properties of ozone-modified germicidal oils and the specificity of electroformed materials, it is possible to obtain a fundamentally new product with improved characteristics.

Another method of introducing the active agent into the fibrillar matrix is the use of encapsulated antimicrobial agents. Numerous studies have developed and successfully tested microcapsules containing ozonolysis products with antimicrobial properties for the manufacture of fibers and fibrillar materials for medical purposes [30, 31]. So, for example, in the case of bioactive textile material, the task of modern developments is to prevent infections in case of osteotrauma, to promote the healing of wound complications, and the general improvement of the body. Ozonated oil capsules are prepared and encapsulated by a coacervation method using GE and GA (GE (from porcine skin, type A) and GA (from the acacia tree)) as the wall material. Usually, the antimicrobial activity of both the oil and the microcapsules is tested [32].

The third methodical approach is the direct treatment of nonwoven fibrous materials with ozone to form bactericidal ozonolysis products. It has been established that the oxygen-containing functional groups formed as a result of the reaction are rather uniformly distributed over the polymer surface [33]. However, due to gaseous diffusion, ozone reacts not only on the surface of the polymer, but also penetrates into the volume, distributing in its amorphous regions.

This review article focuses on recent advances in the modification of nonwovens with ozone and its derivatives to give them anti-inflammatory, antibacterial, or antifungal properties for medical and packaging applications.

1.1 Antibacterial properties

Ozone can play a role in medicine [34, 35] as well as in other areas due to its antibacterial properties and the continued spread of the phenomenon of antibiotic resistance [36–38], that is, the inability of antibiotics to effectively fight infections and bacteria, a phenomenon defined by the excessive and often inappropriate use of antibiotics as for people as well as for animals.

The World Health Organization (WHO) estimated that already hundreds of thousands of people are suffering from antibiotic-resistant infections, and many people are at serious risk. The most dangerous situation is associated with *Escherichia coli*, with a percentage of methicillin resistance of more than 30% [39, 40]. Thus, drug resistance is a serious problem affecting not only public health, but also the development of global progress [41]. The main cause of antibiotic resistance is the mcr-1 gene, which allows bacteria to resist the most potent chemical and pharmaceutical drugs [42, 43]. Bacterial resistance to antibiotics depends on various factors, such as structural changes in the surface membranes of the bacterial cell, which reduce the penetration of the antibiotic. Resistance in Gram-negative bacteria may be related to changes in the protein coat through which many antibiotics penetrate [44].

Generally, most antibiotics have selective selectivity concern to various strains of bacterial microflora. Therefore, the choice of the most effective antibiotic is a sufficiently common problem. One of the universal antibacterial agents is ozone and its derivatives. Ozone has an oxidizing ability that can kill bacteria by attacking the molecular structure of their protective membranes and altering internal enzymes [45]. This mechanism is very similar to that used by leukocytes in bacterial phagocytosis

[46]. It is also extremely effective against viruses, fungi, mold, pesticides, heavy metals, nitrates, nitrites, and other potentially harmful substances [47]. The antibacterial effect of ozone can occur both directly during the treatment of various materials or products with this gas (short-term exposure), and ozone compounds (ozonides) applied to the surface or into the volume of materials (prolonged exposure). The antibacterial effect of ozone can occur both directly during the treatment of various materials or products with this gas (short-term exposure), or ozone derivatives (ozonides) applied to the surface or into the volume of materials (prolonged exposure).

1.2 Ozone obtaining and the ozonolysis process of non-woven materials and oils

Ozone is a triatomic inorganic molecule [48] consisting of three oxygen atoms. It is unstable and under certain conditions, such as pressure and temperature, it decomposes into oxygen atoms with a short life span, due to which it decomposes into its original form after a certain period of time [49].

Since the ozone molecule is unstable, ozone must be used immediately at the point of production. Ozone generators are used to produce ozone. Currently, ozone is produced in industrial conditions in 3 ways:

- By means of UV irradiation [50]. Air containing oxygen or purified oxygen is passed through a special chamber, where, under the influence of short-wave UV radiation, an oxygen molecule dissociates into two atoms, and then ozone is formed by the fusion of an atom and a whole oxygen molecule.

- Electrolytic [51]. It is based on electrochemical reactions: when current is passed through electrolyte solutions placed in special cells, water molecules decompose with the formation of atomic oxygen and then ozone.

- The method of producing ozone by electrosynthesis using a corona discharge [52] is widely used in industry, since it is the most efficient and reliable of all the above. It is distinguished by the optimal ratio of power consumption to the concentration of generated ozone.

The appearance of a corona discharge in a gaseous medium occurs between two high-voltage electrodes separated by a discharge gap and a dielectric in an inhomogeneous electric field, see **Figure 1**.

Ozone is formed as a result of the dissociation of an oxygen molecule under the action of the energy of electrons moving between the electrodes through the discharge gap (**Figure 1**). The ozone concentration depends on the magnitude of the voltage, its frequency, thickness and dielectric constant of the dielectric. In addition, important parameters, in this case, are the concentration of oxygen in the supplied gaseous medium, the type of gas forming it, the pressure, and the degree of purification of oxygen and the gaseous medium.

$$O_2 + e \rightarrow e + O^{\cdot} + O^{\cdot} \quad (1)$$

$$O^{\cdot} + 2O_2 \rightarrow O_3 + O_2 \quad (2)$$

Where, e is a high-energy particle, such as an electron, photon, excited buffer gas atom or molecule, impurities, etc.

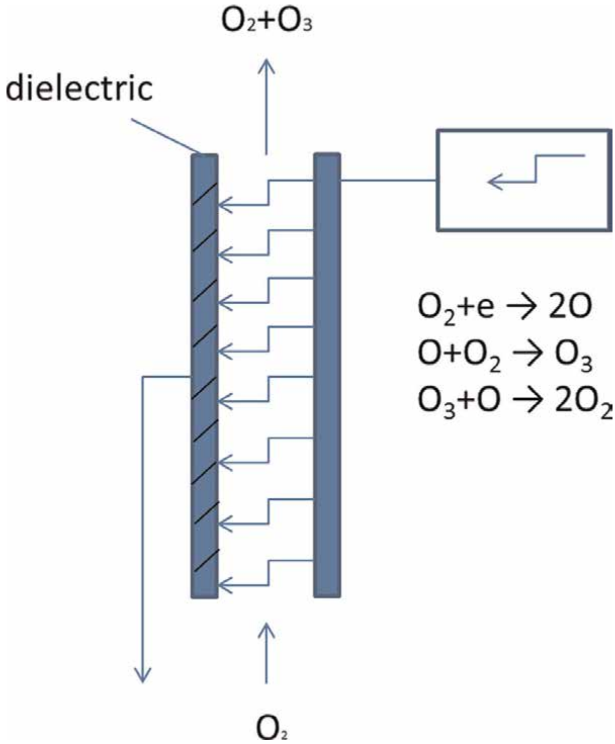


Figure 1.
Corona discharge chamber.

In all sources of ozone synthesis, along with the reactions of its formation (1) and (2), there is also a group of reactions of its decomposition. The latter can be represented as a sequence of chemical processes (3)–(6) [49, 53–55]:

$$O_3 + e \rightarrow O^- + O_2 \quad (3)$$

$$O_3 + O^{\cdot} \rightarrow O_2 + O_2 \quad (4)$$

$$O^{\cdot} + O_3 + O_2 \rightarrow O_3 + O_2 \quad (5)$$

$$O_3 \rightarrow O^{\cdot} + O_2 \quad (6)$$

At moderate and low concentrations, the advantage of ozone is its environmental friendliness, which expands the scope of its application as an oxidizing agent, fungicide, deodorizer, and disinfectant. The production and use of ozone does not lead to secondary pollution of the environment, and it does not produce unwanted by-products. Unused ozone, decaying, again turns into gaseous diatomic oxygen.

Ozone has a high oxidizing ability, due to which it is able to act on bacteria, protozoa, viruses, and fungi, breaking the intermolecular bonds of high-molecular compounds and violating the integrity of their shells. Due to these properties, ozone is widely used in various fields of medicine, in particular, as a substitute for antibiotics [56] and medicines, to which resistance has developed in the microbial environment in recent years [57]. Ozone therapy is a medical approach that has become widespread in some regions of Europe and South America [58]. The properties of ozone also have a positive impact in the agricultural sector: in the cultivation and production of plants to replace chemical and pharmaceutical products; in the food, industrial, textile, and paper industries; and in water disinfection, both for drinking water [59] and waste-water treatment [26].

Ozone successfully competes with other disinfectants, such as Cl-derivatives [60], providing, unlike the latter, a safe bactericidal treatment that does not involve the use of chlorine and chlorides and the formation of dioxins. In-resort areas and wellness centers today, most pools and spas use predominantly ozonized water. Ozone practically does not change the characteristics of water, especially its taste and clarity, and drastically reduces the content of harmful by-products.

Ozone has a special effect on vegetable oils. Due to the unsaturated carbon chemical bonds found in their molecular structure, ozone is able to enter into a chemical reaction with the formation of ozonides. These compounds have unique properties that allow the use of these compounds in medicine, cosmetology, and packaging.

1.3 Ozonated oils

Olive oil and its wide range of medicinal properties have been known to mankind for thousands of years. Hippocrates also advised the use of olive juice to treat ulcers and alleviate mental illness. Later, in the Middle Ages, olive oil was used in the treatment of heart disease, gynecological infections, and even fever. It has been demonstrated that it is possible to further improve the properties of oils by treating them with ozone.

Treatment of vegetable oils with ozone is also being actively studied. When treated with ozone, gaseous ozone dissolves in vegetable oils and forms ozonides [61]. For example, when vegetable oils are ozonized, ozone reacts with the unsaturated triacylglycerols contained in them (**Figure 2**). The ozonation of olefins is usually considered within the framework of the mechanism postulated by Criegee [62]. This mechanism describes the reaction of unsaturated ozone to form the initial unstable primary ozonide molecule (R - C - O_3 - C - R’). This primary ozonide readily decomposes to form the zwitterion and the carbonyl groups. These groups can then combine to form a trioxolane compound, which is a non-toxic, biocompatible, and biodegradable material [63, 64], may be a promising additive for introduction into a fibrous matrix.

The ozonides obtained in the process are responsible for the broad biological activity of ozonized vegetable oils. The introduction of ozonized oils in the polymer matrix is possible only if the process is low-temperature, since the formation from the melt may completely decompose the ozonized oil, and all the antibacterial properties necessary for the future product will be lost. One of the possible low-temperature methods for preparing nonwoven mats is electrospinning (**Figure 3**).

1.4 Electrospinning and its basic principles

Electrospinning involves an electrohydrodynamic process during which a drop of liquid is electrified to create a jet, followed by stretching and elongation to form fibers [65]. As shown in **Figure 3** (A and B), the basic setup consists of a high voltage AC or DC power supply, a syringe pump, a spinneret, usually a needle, and a conductive collector. During electrospinning, theliquid is squeezed out of the spinneret, forming a suspended drop due to surface tension [66]. Due to the electrostatic repulsion of surface charges of the same sign during electrization, a liquid drop is deformed into a

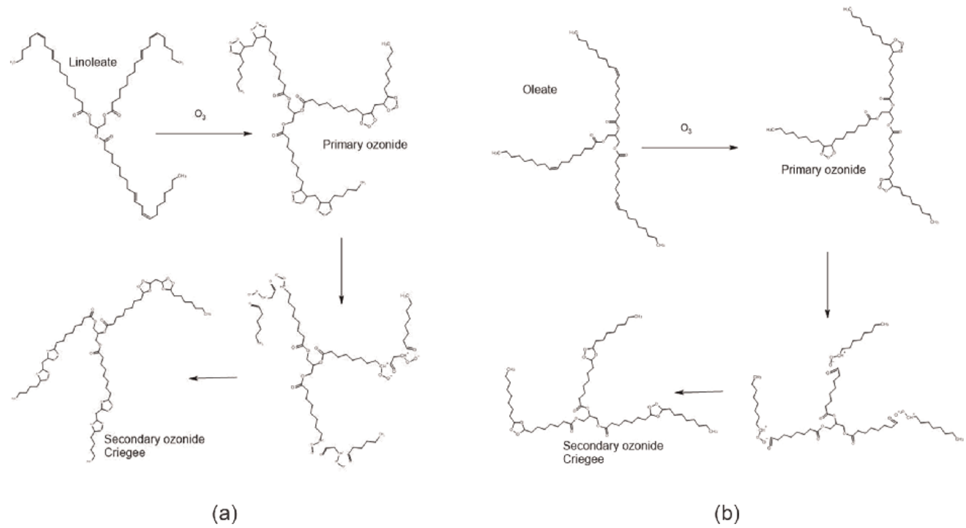


Figure 2.
Chemical structures of ozonated derivatives are formed by the chemical reaction of ozone with unsaturated triglycerides: Trilinoleate (a) and Trioleate (B). The primary ozonides are transient, unstable species that rearrange in the normal, secondary ozonides also known as Criegee ozonides.

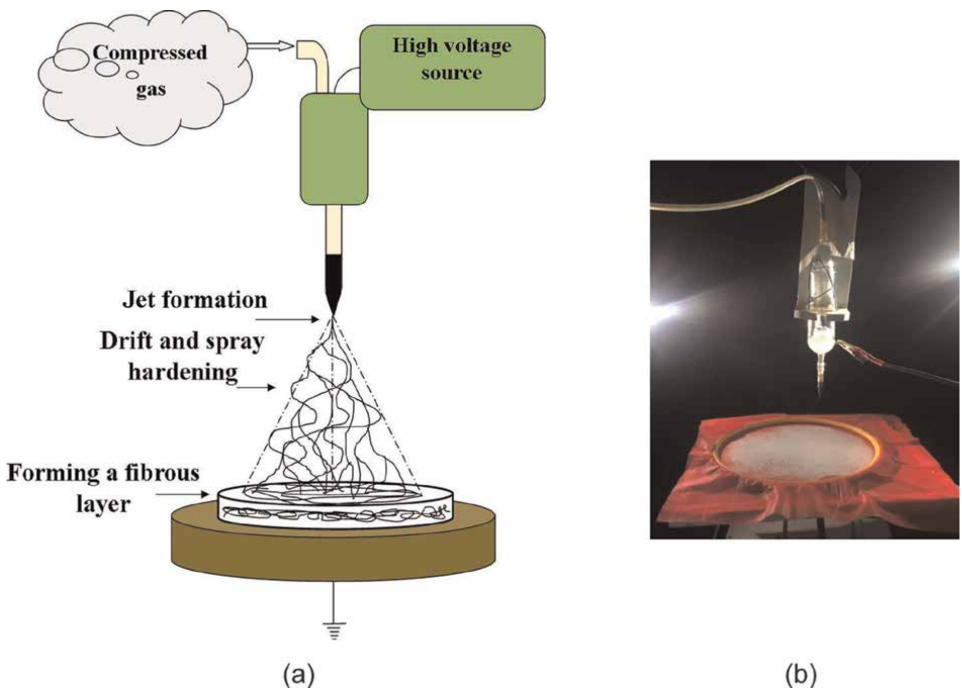


Figure 3.
Schematic illustration showing the electrospinning process (a) and the process of obtaining ultra-fibrous material (b).

Taylor cone, from which a charged jet is ejected. At first, the jet propagates in a straight line, and then, due to the instability of the bend, it makes energetic movements. As the jet expands to smaller diameters, it rapidly solidifies, resulting in the deposition of hard fibers on the horizontal collector [67].

The formation of electrospun fibers and the control of their diameters are largely determined by the applied voltage, fluid flow rate, and the distance between the spinneret tip and the collector.

1.5 Introduction of ozonated oils directly into the non-woven fiber

Combining the plasticizing properties of ozonized oils with active antimicrobial activity and the properties of electroformed mats, we obtain a promising product with improved characteristics.

The authors [29] succeeded in introducing the oil ozonation product, glycerol (9,10-trioxolane) trioleate (ozonide of oleic acid triglyceride (OTOA)), into the electrospinning polymer matrix to obtain highly porous medical fibers. Fundamentally, new non-woven mats based on PLA with the addition of OTOA (1, 3, and 5 wt. %) were obtained. Modified non-woven mats have improved characteristics: improved tissue morphology, thermal, physical-mechanical, and physico-chemical properties compared to unmodified fabrics (**Figure 4**).

Fiber diameter measurements for PLA nonwoven fiber mats with different OTOA content showed that the neat PLA fiber mats had an average fiber diameter of

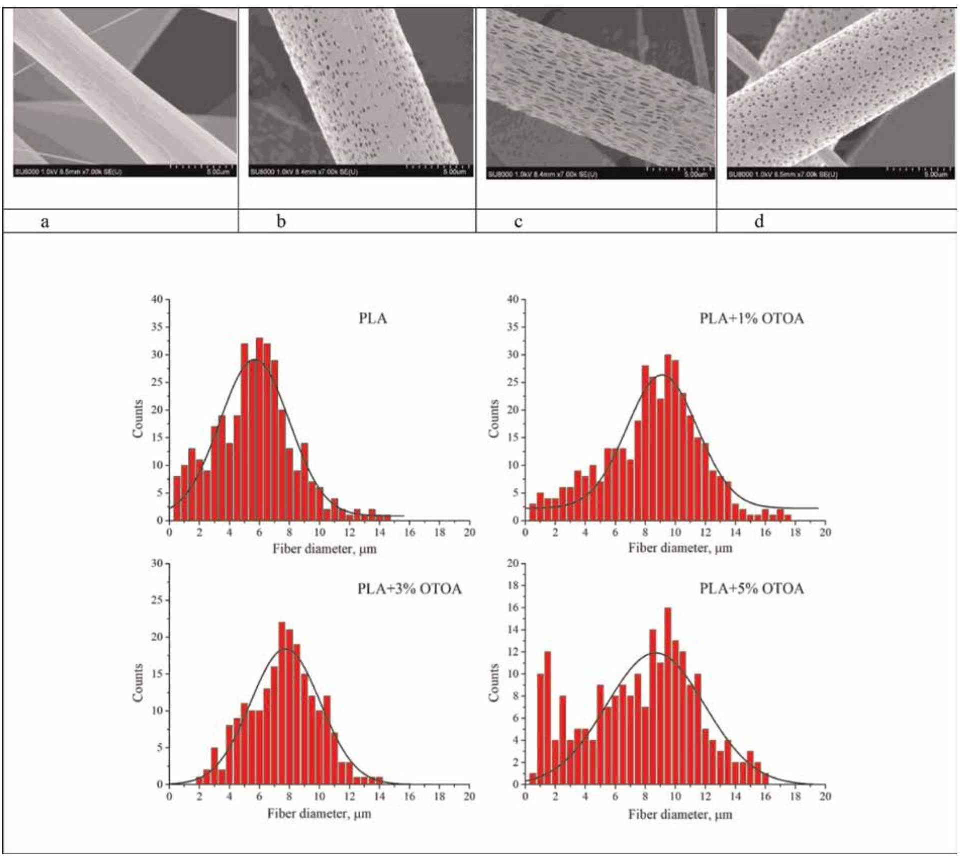


Figure 4.
SEM images of nonwoven fiber PLA mats and magnified monofilaments: Pristine PLA (a, b), PLA + 1% OTOA (c, d), PLA + 3% OTOA (e, f), PLA + 5% OTOA (g, h). Distributions of fiber diameters for studied PLA fibrous samples [29].

5.7 ± 2.3 μm, while the effect of adding OTOA was to increase the average fiber diameter from 5.7 μm to 8–9 μm, observed for all samples containing OTOA. The PLA fiber material with 3% OTOA showed the most uniform fiber size distribution. Analysis of the surface of pure PLA fibers showed no pores in the high magnification SEM image, while samples of PLA with the addition of OTOA clearly show the presence of mesopores distributed over the entire surface of the fiber. The pores have an arbitrary shape with sizes in the range of 0.2–1 μm.

Accordingly, an increase in fiber porosity increases its sorption characteristics. Since the medical applications of fibrous materials require contact with various water-containing physiological media, a study was made of the sorption capacity of PLA-OTOA fibrous mats. An unmodified PLA mat and a similar mat with 1% OTOA substance are characterized by a low sorption capacity compared to samples containing 3% OTOA. With an increase in the total porosity of the fiber, its sorption capacity also grows symbatically. The effect of increasing porosity was confirmed by measurements of the specific surface area of PLA fiber mats, which were obtained by nitrogen adsorption. The specific surface of the fibrous material (S, m2/g) increased significantly with the addition of OTOA, reaching a maximum value of 3.1 m2/g at an OTOA content of 3%.

The DSC results demonstrate a significant effect of the amount of OTOA introduced on the degree of crystallinity of the final material. Analyzing the obtained results, we can conclude that the introduction of an OTOA additive into PLA fibers leads to a plasticizing effect, which is expressed in a noticeable decrease in the cold crystallization temperature of 20.5°C, a decrease in the glass transition temperature by 6°C, and a change in the melting temperature of the polymer (−4, 5°C). All these phenomena are unequivocally associated with an increase in PLA segmental mobility due to plasticization. In this case, a decrease in the enthalpy of cold crystallization and the degree of crystallinity of the fibers from 16.3 to 7.3% was observed, which should also be associated with the destruction of a part of the crystal structure under the action of the plasticizer.

Changes in the structure of modified PLA mats have a significant impact on their mechanical characteristics. The PLA fibrous material with 1% OTOK showed a significantly improved tensile strength compared to the original PLA. With the introduction of 1% OTOK, the relative elongation slightly increases compared to the original PLA, however, the addition of 3% OTOK significantly improves the elongation of the material by more than 30%. For the PLA+ OTOA 5% sample, a moderate decrease in elongation is observed. Such a behavior of the mechanical properties of the modified fibers directly indicates the plasticizing effect from the introduction of OTOA, which is directly related to the change in the structural-dynamic state of the amorphous regions of PLA.

The obtained results of the study of electroformed PLA mats modified by OTOA indicate the possibility of controlling the morphology of the obtained materials; their water absorption capacity, as well as thermal and mechanical properties by varying the OTOA content in the PLA matrix. Thus, the nonwoven PLA material with 3% OTOA showed the best functional characteristics among all studied PLA + OTOA samples, providing highly porous surface morphology, increased specific surface area and high water sorption.

The mechanical properties of this material showed increased strength and elasticity of PLA + 3% OTOA. The chemical interaction between the PLA matrix and OTOA is confirmed by the FT-IR results. Analysis of DSC data and mechanical testing indicates an improvement in the thermal and mechanical properties of PLA mats plasticized with OTOA.

However, the interaction of OTOA (5%) with PLA polymer chains leads to a deterioration in the morphological and mechanical properties of the fibrous material due to the difficulty in the segmental movement of the ends of the PLA polymer, the plasticizing effect of OTOA weakens.

The developed modified material PLA + OTOA has optimal physicochemical properties at an additive content of 3%.

Such a material can be used in various biomedical applications as a pioneering nonwoven material with pronounced antibacterial activity, for drug delivery, and in tissue engineering, since the plasticizing effect of OTOA leads to a noticeable improvement in the morphology of electrospun materials, their mechanical properties, and an improvement in sorption capacity. The pronounced antimicrobial activity of OTOA [68, 69] suggests its possible use as a functional antibacterial additive.

1.6 Microencapsulation of ozonated oils

Another method of incorporating an active agent into a fibrous biodegradable polymer matrix is the use of encapsulated ozone-generating antimicrobial agents. In the course of numerous studies, microcapsules of ozonized active agents (oils) with antimicrobial activity have been developed and successfully applied for the manufacture of nonwoven materials for medical purposes. Encapsulation is defined as the process by which bioactive oil droplets are coated or embedded in a homogeneous or heterogeneous matrix to form small capsules with many beneficial properties [64, 70, 71]. Encapsulation of oils is an effective approach to improve their stability, non-volatility, and environmental protection. The design goal of any bioactive textile is to prevent infections in the event of injury, promote healing, and improve health. Ozonated oil capsules are prepared and encapsulated by a coacervation method using GE and GA (GE (from porcine skin, type A) and GA (from the acacia tree)) as the wall material. Typically, both the oil and the microcapsules are tested for antimicrobial activity.

Microencapsulation of ozonized red pepper seed oil has been proposed by Özyildiz et al. [30] with application in non-woven fabric for the production of antimicrobial textile material. The ozonated oil was microencapsulated by coacervation using gelatin and gum arabic and materials in the presence of a surfactant. Particle batches with a particle size of 19–37 μm and an oil content of 47–56% were obtained. Antimicrobial activity against *E. coli*, *Pseudomonas aeruginosa*, MRSA, *Candida. albicans*, and vancomycin-resistant Enterococcus faecium showed that the encapsulated ozonated oil retained its efficacy in microcapsule form. It has been established that tissues impregnated with active microcapsules are also very active against antibiotic-resistant test microorganisms. The observed sustained activity is extremely important for the production of functional medical textiles with antimicrobial and wound healing properties.

Such materials are actively studied in the literature (Besen et al.) [72]. For example, St. John's wort oil and linseed oil were ozonized and then encapsulated by a simple coacervation method. Ozonated oils consistently show high antibacterial activity due to the presence of ozonide structures. The same idea was tried to apply an antibacterial finish to cotton fabrics using the incorporation of ozonated oils into cyclodextrin complexes by Beşen et al. [73]. These complexes provide the molecules with increased solubility and physical-chemical stability. From the results of the TGA evaluation, the authors observed that the thermal stability increased when the ozonated oil was isolated in the inclusion complex. The unpleasant smell of ozonized oil has completely disappeared.

The products of vegetable oils oxidation with ozone in appropriate formulations can be used for the prevention and treatment of local chronic infections. Ozone therapy can be used as an alternative to local antimicrobial agents. The widespread use of topical agents such as mupirocin and fusidic acid has already led to the emergence of bacterial resistance, predominantly in staphylococci [73].

Also, quite an urgent problem is the sterilization of polymeric materials and products before packaging or use. This is particularly important for medical devices and materials and food packaging. During treatment with ozone, the chemical structure of the polymer material in the surface layers usually changes. Oxygen-containing groups are formed, and as a result, the material's hydrophilicity increases. Longer treatment with ozone results to the destruction of macromolecular chains in the surface layers of the polymer.

1.7 Ozone surface treatment of nonwoven fabrics

Another widely used surface modification strategy is the introduction of reactive groups onto the surface of the nanofiber mat through plasma treatment or special chemical reactions such as with ozone. One of the widely used methods for the introduction of active groups on the surface of nanofibers is the surface treatment of materials in plasma. During processing, polar groups such as -COOH and -OH can form on the surface of polymeric materials. Their concentration depends on the conditions and duration of treatment. For example, by using plasma, the properties of PCL nanofibers, its hydrophilicity and increased bio-efficiency, have been improved [74, 75].

Further, other compounds can be grafted onto the active groups obtained as a result of processing: small molecules or large molecules of medicinal substances [76]. For example, radical polymerization has been initiated through functional groups on the surface of nanofibers, leading to the production of heat-sensitive and solvent-resistant nanofibers. Another methodological approach is the direct treatment of nonwoven fibrous materials with ozone to form a bactericidal ozonolysis product. It has been established that the functional groups formed as a result of the reaction are predominantly uniformly distributed over the polymer surface. However, due to gaseous diffusion, ozone reacts not only on the surface of the polymer, but also penetrates into its volume through its imperfections or through the amorphous region of materials.

In [33], the effect of ozone on the supramolecular structure of PHB fibers produced by electrospinning revealed a change in tensile strength as a result of the duration of ozonolysis. At the initial stage of ozonation, a significant increase in tensile strength was found. The highest value was reached by the 7th minute of ozone treatment. Gaseous ozone is a strong oxidant that can significantly affect the morphology of polymers, the structure of macromolecules, and crystallinity [77, 78]. Treatment with ozone has a number of advantages over, for example, oxygen treatment. Thus, in a short period of contact with a polymer material, significant results can be achieved in terms of sterilization of its surface. However, the effect of ozone on the structural and dynamic characteristics of polymers used in packaging and medical materials is different and requires extensive study. Often, under improperly selected conditions for ozone treatment of polymer fibers, the destruction of the polymer chain is observed, which leads to a decrease in the average molecular weight and an increase in segment mobility.

During ozonation, a primary increase in the degree of crystallinity is observed, which is apparently associated with the strengthening of intercrystalline polymer molecules in the amorphous PHB phase. The oxidative process starts from the surface of the material, namely, from the oxidation of the side groups.

It is known from the literature [79] that deep oxidation of a material results in "chemical relaxation" of the most rigid macromolecules in the amorphous polymer phase. The relaxation mechanism proceeds at a faster rate [80, 81]. Further ozonation leads to orientation of PHB chains and an increase in the crystallinity of the material [82]. After that, the PHB chains are partially destroyed. The process stops completely after 10 min of ozonation, and gradual degradation was observed (**Figure 5**).

As can be seen from the above studies, the ozonation of fibrous materials based on PHB leads to the ordering of the supramolecular structure, which has a beneficial effect on the complex of physicomechanical properties. Simultaneously with this, ozone can diffuse into the bulk of the fiber and interact with polymer chains in interfibrillar amorphous regions to form both ozonides and active radicals. In this regard, the question arises: will the non-woven fibrous biopolymer material have

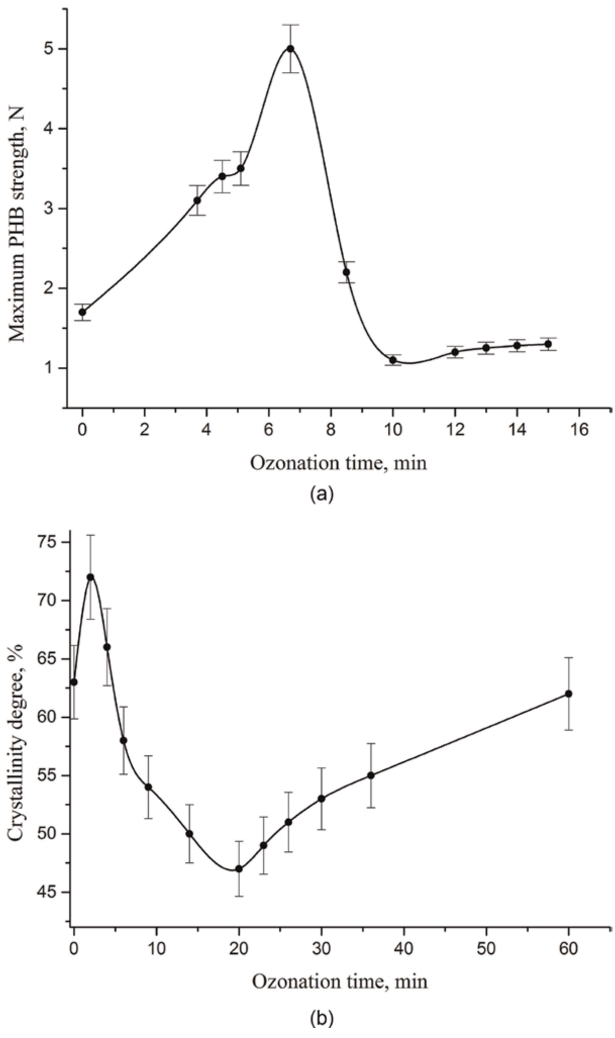


Figure 5.
PHB maximum strength versus ozonation time in min(a), crystallinity degree versus ozonation time in min (b).

bactericidal properties after ozonation and how long will this effect last? There is no answer to this question yet. There are no studies in this area in the literature. However, if it is possible to experimentally establish the presence and duration of the bactericidal effect after ozonation of the material, this would open up the possibility of creating antibacterial packaging, disposable polymeric tableware, and medical items, without adding antibacterial substances to their composition.

2. Conclusion

On the basis of this review of state-of-the art scientific research, it can be concluded that the study of ozone compounds and the process of ozonolysis of biopolymer materials is promising for various biopolymer applications. Ozone not only has a beneficial effect on the human's physiological functions, but is also one of the most promising antibacterial agents. Surface properties of the biopolymer materials could change under the influence of ozone. During deep ozonolysis of biopolymer films and fibers, changes also occur in their supramolecular structure, which is reflected in the number physical and mechanical parameters, such as hydrophilicity, smoothness, elasticity, strength, antimicrobial activity. Recent works related to the ozonolysis of vegetable oils and application of the resulting ozonides as antibacterial functional additives in the polymer films and ultrathin fibers are also of particular attention and interest. These materials have good physical and mechanical properties and high antibacterial activity. Biopolymer materials containing ozonides could be widely used in the treatment of infectious (bacterial and viral) diseases, traumatology, orthopedics, cosmetology, and hygiene.

Conflict of interest

The authors declare no conflict of interest.

Author details

Olga Alexeeva[1]*, Valentina Siracusa[2], Marina L. Konstantinova[1], Anatoliy A. Olkhov[3,4], Alexey L. Iordanskii[3]* and Alexandr A. Berlin[3]

1 N.M. Emanuel Institute of Biochemical Physics, Russian Academy of Sciences, Moscow, Russia

2 Department of Chemical Science (DSC), University of Catania, Catania, Italy

3 N.N. Semenov Federal Research Center for Chemical Physics, Russian Academy of Sciences, Moscow, Russia

4 Academic Department of Innovational Materials and Technologies Chemistry, Plekhanov Russian University of Economics, Moscow, Russia

*Address all correspondence to: alexol@yandex.ru and aljordan08@gmail.com

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Yilmaz KB, Sabuncuoglu B, Yildirim B, Silberschmidt VV. A brief review on the mechanical behavior of nonwoven fabrics. Journal of Engineered Fibers and Fabrics. 2020;**15**:1-9. DOI: 10.1177/1558925020970197

[2] Batra SK, Pourdeyhimi B. Introduction to Nonwovens Technology (Engineering with Fibers). 1st ed. DEStech Publications: Lancaster, Pennsylvania, Inc.; 2012, ISBN: 978-1-60595-037-2. p. 366

[3] Russell S. Handbook of Nonwovens (Woodhead Publishing Series in Textiles). 1st ed. Cambridge, England: Woodhead Publishing; 2006, ISBN: 978-1-85573-603-0. p. 530

[4] Luo X, Cheng P, Wang W, Fu J, Gao W. Established an eco-friendly cotton fabric treating process with enhancing anti-wrinkle performance. Journal of Engineered Fibers and Fabrics. 2021;**16**:1-11. DOI: 10.1177/15589250211003454

[5] Granados A, Pleixats R, Vallribera A. Recent advances on antimicrobial and anti-inflammatory cotton fabrics containing nanostructures. Molecules. 2021;**26**:3008. DOI: 10.3390/molecules26103008

[6] Román LE, Gomez ED, Solís JL, Gómez MM. Antibacterial cotton fabric functionalized with copper oxide nanoparticles. Molecules. 2020;**25**:5802. DOI: 10.3390/molecules25245802

[7] Gherasim O, Puiu RA, Bîrca AC, Burdusel AC, Grumezescu AM. An updated review on silver nanoparticles in biomedicine. Nanomaterials. 2020;**10**: 2318. DOI: 10.3390/nano10112318

[8] Seth M, Jana S. Nanomaterials based superhydrophobic and antimicrobial coatings. Nano World Journal. 2020;**6**: 26-28. DOI: 10.17756/nwj.2020-077

[9] Han JH. Chapter 6 - Antimicrobial packaging systems. In: Han JH, editor. Food Science and Technology, Innovations in Food Packaging. Cambridge, MA, USA: Academic Press; 2005. pp. 80-107. DOI: 10.1016/B978-012311632-1/50038-3

[10] Mandal TK. Chapter 18 - ZnO nanostructures for food packaging applications. In: Abd-Elsalam KA, editor. Nanobiotechnology for Plant Protection, Zinc-Based Nanostructures for Environmental and Agricultural Applications. Cambridge, MA, USA: Elsevier; 2021. pp. 367-384. DOI: 10.1016/B978-0-12-822836-4.00024-0

[11] Asgher M, Qamar SA, Bilal M, Iqbal HMN. Bio-based active food packaging materials: Sustainable alternative to conventional petrochemical-based packaging materials. Food Research International. 2020;**137**:109625. DOI: 10.1016/j.foodres.2020.109625

[12] Paletta A, Filho WL, Balogun A-L, Foschi E, Bonoli A. Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy. Journal of Cleaner Production. 2019;**241**:118149. DOI: 10.1016/j.jclepro.2019.118149

[13] Ahmed T, Shahid M, Azeem F, Rasul I, Shah AA, Noman M, et al. Biodegradation of plastics: Current scenario and future prospects for environmental safety. Environmental Science and Pollution Research. 2018; **25**(8):7287-7298. DOI: 10.1007/s11356-018-1234-9

[14] Iordanskii AL, Ol'khov AA, Karpova SG, Kucherenko EL, Kosenko R.Yu,

Rogovina SZ, et al. Influence of the structure and morphology of ultrathin poly(3-hydroxybutyrate) fibers on the diffusion kinetics and transport of drugs // Polymer Science, Series A. 2017;**59**(3):343-353. DOI: 10.1134/S0965545X17030075

[15] Ol'khov AA, Karpova SG, Lobanov AV, Tyubaeva PM, Gol'tsova LI, Kucherenko EL, et al. Ultrathin poly(3-hydroxybutyrate) fibers modified with the iron(III) complex of Tetraphenylporphyrin. Fibre Chemistry. 2017;**49**(3):217-221. DOI: 10.1007/s10692-017-9871-1

[16] Tyubaeva P, Varyan I, Lobanov A, Olkhov A, Popov A. Effect of the hemin molecular complexes on the structure and properties of the composite electrospun materials based on poly(3-Hydroxybutyrate). Polymers. 2021;**13**(22): 4024. DOI: 10.3390/polym13224024

[17] Karpova SG, Chumakova NA, Lobanov AV, Olkhov AA, Vetcher AA, Iordanskii AL. Evaluation and characterization of ultrathin poly(3-hydroxibutirate) fibers loaded with Tetraphenylporphyrin and its complexes with Fe(III) and Sn(IV). Polymers. 2022; **14**:610. DOI: 10.3390/polym14030610

[18] Sung S-Y, Sin LT, Tee T-T, Bee S-T, Rahmat AR, Rahman WAWA, et al. Antimicrobial agents for food packaging applications. Trends in Food Science & Technology. 2013;**33**(2):110-123. DOI: 10.1016/j.tifs.2013.08.001

[19] Cooksey K. Active packaging and the shelf life of foods. In: Robertson GL, editor. Food Packaging and Shelf Life, a Practical Guide. Boca Raton, Florida: CRC Press; 2010. p. 82, 373–374. DOI: 10.1201/9781420078459-c20

[20] Mamidi, N.; Zuníga, A.E; Villela-Castrejón, J. Engineering and evaluation of forcespun functionalized carbon nano-onions reinforced poly (ε-caprolactone) composite nanofibers for pH-responsive drug release. Materials Science & Engineering C. 2020;**112**:110928. DOI: doi.org/10.1016/j.msec.2020.110928

[21] Reneker DH, Yarin AL. Electrospinning jets and polymer nanofibers. Polymer. 2008;**49**:2387-2425. DOI: doi.org/10.1016/j.polymer.2008.02.002

[22] Mokhena TC, Jacobs V, Luyt AS. A review on electrospun bio-based polymers for water treatment. Express Polymer Letters. 2015;**9**:839-880. DOI: doi.org/10.3144/expresspolymlett.2015.79

[23] Dziemidowicz K, Brocchini S, Williams GR. A simple route to functionalising electrospun polymer scaffolds with surface biomolecules. International Journal of Pharmaceutics. 2021;**597**:120231. DOI: doi.org/10.1016/j.ijpharm.2021.120231

[24] Park J, Lee I. Controlled release of ketoprofen from electrospun porous polylactic acid (PLA) nanofibers. Journal of Polymer Research. 2011;**18**:1287-1291. DOI: 10.1007/s10965-010-9531-0

[25] Lunin VV, Samoilovich VG, Tkachenko SN, Tkachenko IS. Ozone Production and Application. Theory and Practice. Moscow University Press; 2016

[26] Fiessinger F, Richard Y, Montiel A, Musquere P. Advantages and disadvantages of chemical oxidation and disinfection by ozone and chlorine dioxide. Science of the Total Environment. 1981;**18**:245-261. DOI: 10.1016/S0166-1116(08)70851-3

[27] Radzimierska-Kaźmierczak M, Śmigielski K, Sikora M, Nowak A, Plucińska A, Kunicka-Styczyńska A,

et al. Olive oil with ozone-modified properties and its application. Molecules. 2021;**26**:3074. DOI: 10.3390/molecules26113074

[28] Georgiev VF, Batakliev TT, Anachkov MP, Rakovski SK. Study of Ozonated olive oil: Monitoring of the ozone absorption and analysis of the obtained functional groups. Ozone: Science & Engineering. 2015;**37**:55-61. DOI: 10.1080/01919512.2014.904736

[29] Olkhov A, Alexeeva O, Konstantinova M, Podmasterev V, Tyubaeva P, Borunova A, et al. Effect of Glycero-(9,10-trioxolane)-trialeate on the physicochemical properties of non-woven Polylactic acid fiber materials. Polymers. 2021;**13**:2517. DOI: 10.3390/polym13152517

[30] Özyildiz F, Karagönlü S, Basal G, Uzel A, Bayraktar O. Micro-encapsulation of ozonated red pepper seed oil with antimicrobial activity and application to nonwoven fabric. Letters in Applied Microbiology. 2013;**56**:168-179. DOI: 10.1111/lam.12028

[31] Tavaria FK, Soares JC, Reis IL, Paulo MH, Malcata FX, Pintado ME. Chitosan: Antimicrobial action upon staphylococci after impregnation onto cotton fabric. Journal of Applied Microbiology. 2012;**112**:1034-1041. DOI: 10.1111/j.1365-2672.2012.05274.x

[32] Bakry AM, Abbas S, Ali B, Majeed H, Abouelwafa MY, Mousa A, et al. Microencapsulation of oils: A comprehensive review of benefits, techniques, and applications. Comprehensive Reviews in Food Science and Food Safety. 2016;**15**:143-182. DOI: 10.1111/1541-4337.12179

[33] Tyubaeva P, Zykova A, Podmasteriev V, Olkhov A, Popov A, Iordanskii A. The investigation of the structure and properties of ozone-sterilized nonwoven biopolymer materials for medical applications. Polymers. 2021;**13**:1268. DOI: 10.3390/polym13081268

[34] Martínez SG, Al-Dalain SM, Menéndez S, Re L, Giuliani A, Candelario JE, et al. Therapeutic efficacy of ozone in patients with diabetic foot. European Journal of Pharmacology. 2005;**523**:151-161. DOI: 10.1016/j.ejphar.2005.08.020

[35] Smith NL, Wilson AL, Gandhi J, Vatsia S, Khan SA. Ozone therapy: An overview of pharmacodynamics, current research, and clinical utility. Medical Gas Research. 2017;**7**:212-219. DOI: 10.4103/2045-9912.215752

[36] Spit T, van der Hoek JP, de Jong C, van Halem D, de Kreuk M, Perez BB. Removal of antibiotic resistance from municipal secondary effluents by ozone-activated carbon filtration. Frontiers in Environmental Science. 2022;**10**:834577. DOI: 10.3389/fenvs.2022.834577

[37] Blair JMA, Webber MA, Baylay AJ, Ogbolu DO, Piddock LJV. Molecular mechanisms of antibiotic resistance. Nature Reviews. Microbiology. 2015;**13**:42-51. DOI: 10.1038/nrmicro3380

[38] Fair RJ, Tor Y. Antibiotics and bacterial resistance in the 21st century. Perspectives in Medicinal Chemistry. 2014;**6**:25-64. DOI: 10.4137/PMC.S14459

[39] Valdenassi L, Franzini M, Garbelli P, Camolese M. Oxygen-ozone activity in making factory farms antibiotic-free for prevention of antibiotic resistance. Ozone Therapy. 2016;**1**:42-44. DOI: 10.4081/ozone.2016.6274

[40] Tacconelli E, Carrara E, Savoldi A, Harbarth S, Mendelson M, Monnet DL, et al. Discovery, research, and development of new antibiotics: The WHO priority list of antibiotic-resistant

bacteria and tuberculosis. The Lancet Infectious Diseases. 2018;**18**:318-327. DOI: 10.1016/S1473-3099(17)30753-3

[41] Jasovsky D, Littmann J, Zorzet A, Cars O. Antimicrobial resistance—A threat to the world's sustainable development. Upsala Journal of Medical Sciences. 2016;**121**:159-164. DOI: 10.1080/03009734.2016.1195900

[42] Liu Y-Y, Wang Y, Walsh TR, Yi L-X, Zhang R, Spencer J, et al. Emergence of plasmid-mediated colistin resistance mechanism MCR-1 in animals and human beings in China: A microbiological and molecular biological study. The Lancet Infectious Diseases. 2016;**16**:161-168. DOI: 10.1016/S1473-3099(15)00424-7

[43] Skov RL, Monnet DL. Plasmid-mediated colistin resistance (mcr-1 gene): Three months later, the story unfolds. Eurosurveillance. 2016;**21**: 30155. DOI: 10.2807/1560-7917.ES.2016.21.9.30155

[44] Rice LB. Federal Funding for the study of antimicrobial resistance in nosocomial pathogens: No ESKAPE. The Journal of Infectious Diseases. 2008;**197**:1079-1081. DOI: 10.1086/533452

[45] Czekalski N, Imminger S, Salhi E, Veljkovic M, Kleffel K, Drissner D, et al. Inactivation of antibiotic resistant bacteria and resistance genes by ozone: From laboratory experiments to full-scale wastewater treatment. Environmental Science & Technology. 2016;**50**:11862-11871

[46] Liao J, Ren J, Wei H, Lam RHW, Chua SL, Khoo BL. Label-free biosensor of phagocytosis for diagnosing bacterial infections. Biosensors & Bioelectronics. 2021;**191**:113412. DOI: 10.1016/j.bios.2021.113412

[47] Moat J, Cargill J, Shone J, Upton M. Application of a novel decontamination process using gaseous ozone. Canadian Journal of Microbiology. 2009;**55**(8): 928-933. DOI: 10.1139/w09-046

[48] Dimitrov A, Seppelt K, Scheffler D, Willner H. Chemical synthesis of ozone, isotopic labeling, and redistribution. Journal of the American Chemical Society. 1998;**120**(34):8711-8714. DOI: 10.1021/ja980887n

[49] Eliasso B, Hirth M, Kogelschatz U. Ozone synthesis from oxygen in dielectric barrier discharges. Journal of Physics D Applied Physics. 1987; **20**(11):1421. DOI: 10.1088/0022-3727/20/11/010

[50] Claus H. Ozone generation by ultraviolet lamps. Photochemistry and Photobiology. 2021;**97**:471-476. DOI: 10.1111/php.13391

[51] De Sousa LG, Franco DV, Da Silva LM. Electrochemical ozone production using electrolyte-free water for environmental applications. Journal of Environmental Chemical Engineering. 2016;**4**(1):418-427. DOI: 10.1016/j.jece.2015.11.042

[52] Gibalov VI, Samoilovich VG, Filippov YV. Russian Journal of Physical Chemistry. 1981;**55**:471-479

[53] Eliasson B, Kogelschatz U. Basic Data for Modelling of Electrical Discharges in Gases: Oxygen. Report KLR86-11C. CH54–05 Baden: Asea Brown Boveri Konzernforschung; 1986

[54] Yanallah K, Pontiga F, Castellanos A. Numerical simulation of an oxygen-fed wire-to-cylinder negative corona discharge in the glow regime. Journal of Physics D: Applied Physics. 2011;**44**: 055201. DOI: 10.1088/0022-3727/44/5/055201

[55] Loiseau JF, Lacassie F, Monge C, Peyrous R, Held B. Numerical simulation of ozone axial and radial distribution in a cylindrical oxygen-fed ozonizer. Journal of Physics D: Applied Physics. 1994; **27**(1):63-73

[56] Yoon Y, He H, Dodd MC, Lee Y. Degradation and deactivation of plasmid-encoded antibiotic resistance genes during exposure to ozone and chlorine. Water Research. 2021;**202**: 117408. DOI: 10.1016/j.watres.2021. 117408 Epub 2021 Jul 6

[57] Tambe SM, Sampath L, Modak SM. In vitro evaluation of the risk of developing bacterial resistance to antiseptics and antibiotics used in medical devices. The Journal of Antimicrobial Chemotherapy. 2001;**47**: 589-598

[58] Zeng J, Lu J. Mechanisms of action involved in ozone-therapy in skin diseases. International Immunopharmacology. 2018;**56**:235-241

[59] Von Gunten U. The basics of oxidants in water treatment. Part B: Ozone reactions. Water Science and Technology. 2007;**55**(12):25-29. DOI: 10.2166/wst.2007.382

[60] Haag WR, Hoigné J. Ozonation of water containing chlorine or chloramines. Reaction products and kinetics. Water Research. 1983;**17**: 1397-1402

[61] Georgiev V, Anachkov M, Batakliev T, Rakovsky S. Study on the stoichiometry and reaction products of extra virgin olive oil ozonation. Bulgarian Chemical Communications. 2013;**45**:203-207

[62] Criegee R. Mechanism of Ozonolisis. 14th ed. England: Angewandte Chemie Int; 1975. DOI: 10.1002/anie.197507451

[63] Zhou Z, Zhou S, Abbatt JPD. Kinetics and condensed-phase products in multiphase Ozonolysis of an unsaturated triglyceride. Environmental Science & Technology. 2019;**53**(21): 12467-12475. DOI: doi.org/10.1021/acs. est.9b04460

[64] de Almeida Kogawa RN, de Arruda EJ, Micheletti AC, de Cepa Matos MF, Silva de Oliveira LC, de Lima DP, et al. Synthesis, characterization, thermal behavior and biological activity of ozonides from vegetable oils. RSC Advances. 2015;**5**: 65427-65436. DOI: 10.1039/C5RA02798E

[65] Davoodi P, Gill EL, Wang W, Shery Huang YY. Chapter 2 - Advances and innovations in electrospinning technology. In: Kasoju N, Ye H, editors. Woodhead Publishing Series in Biomaterials, Biomedical Applications of Electrospinning and Electrospraying. Cambridge, UK: Woodhead Publishing; 2021. pp. 45-81. DOI: 10.1016/b978-0-12-822476-2.00004-2

[66] Rutledge GC, Fridrikh SV. Formation of fibers by electrospinning. Advanced Drug Delivery Reviews. 2007; **59**(14):1384-1391. DOI: 10.1016/j. addr.2007.04.020

[67] Collins RT, Jones JJ, Harris MT, Basaran OA. Electrohydrodynamic tip streaming and emission of charged drops from liquid cones. Nature Physics. 2008; **4**(2):149e154. DOI: 10.1038/nphys807

[68] Ugazio E, Tullio V, Binello A, Tagliapietra S, Dosio F. Ozonated oils as antimicrobial Systems in Topical Applications. Their characterization, current applications, and advances in improved delivery techniques. Molecules. 2020;**25**:334-347. DOI: doi. org/10.3390/molecules25020334

[69] Moureu S, Violleau F, Haimoud-Lekhal DA, Calmon A. Ozonation of

sunflower oils: Impact of experimental conditions on the composition and the antibacterial activity of ozonized oils. Chemistry and Physics of Lipids. 2015; **186**:79-85. DOI: 10.1016/j.chemphyslip.2015.01.004

[70] Rodríguez J, Martín MJ, Ruiz MA, Clares B. Current encapsulation strategies for bioactive oils: From alimentary to pharmaceutical perspectives. Food Research International. 2016;**83**:41-59. DOI: 10.1016/j.foodres.2016.01.032

[71] Santos PDF, Rubio FTV, da Silva MP, Pinho LS, Favaro-Trindade CS. Microencapsulation of carotenoid-rich materials: A review. Food Research International. 2021;**147**:110571. DOI: 10.1016/j.foodres.2021.110571

[72] Beşen BS, Balcı O, Güneşoğlu C, Orhan M, İnci Somuncuoğlu E, İrem Tatlı I. Obtaining medical textiles including microcapsules of the ozonated vegetable oils. Fibers and Polymers. 2017;**18**:1079-1090. DOI: 10.1007/s12221-017-1212-8

[73] Beşen BS, Guneşoğlu C, Balci O, Kahramanmaraş S. Antibacterial finishing of 100% cotton fabric with β-cyclodextrin-ozonated olive oil inclusion complex. AATCC Journal of Research. 2016;**3**:12-18. DOI: 10.14504/ajr.3.6.3

[74] Gupta US, Dhamarikar M, Dharkar A, Chaturvedi S, Kumrawat A, Giri N, et al. Plasma modification of natural fiber: A review. Materials Today: Proceedings. 2021;**43**(Part 1):451-457. DOI: 10.1016/j.matpr.2020.11.973

[75] Diblíková L, Mašek Z, Král M. The effect of carbon fiber plasma treatment on the wettability and interlaminar shear strength of geopolymer composite. Journal of the Australian Ceramic Society. 2019;**55**:1139-1145. DOI: 10.1007/s41779-019-00328-4

[76] Williamson DA, Carter GP, Howden BP. Current and emerging topical Antibacterials and antiseptics: Agents, action, and resistance patterns. Clinical Microbiology Reviews. 2017;**30**: 827-860. DOI: 10.1128/CMR.00112-16

[77] Ding J, Zhang J, Li J, Li D, Xiao C, Xiao H, et al. Electrospun polymer biomaterials. Progress in Polymer Science. 2019;**90**:1-34. DOI: 10.1016/j.progpolymsci.2019.01.002

[78] Shtilman MI. Technology for Obtaining Polymers for Medical and Biological Purposes. Moscow, Russia: Academbook; 2006. pp. 25-309

[79] Odelius K, Plikk P, Albertsson A-C. The influence of composition of porous copolyester scaffolds on reactions induced by irradiation sterilization. Biomaterials. 2008;**29**:129-140. DOI: 10.1016/j.biomaterials.2007.08.046

[80] Greenfeld I, Arinstein A, Fezzaa K, Rafailovich MH, Zussman E. Polymer dynamics in semidilute solution during electrospinning: A simple model and experimental observations. Physics Review. 2011;**84**:041806. DOI: 10.1103/PhysRevE.84.041806

[81] Arinstein A. Supermolecular structure formation during electrospinning, and its effect on electrospun polymer nanofiber unique features. In: Andrianov IV, Manevich AI, Mikhlin YV, Gendelman OV, editors. Problems of Nonlinear Mechanics and Physics of Materials. New York, NY, USA: Springer International Publishing; 2019. pp. 173-204 ISBN: 978-3030063894

[82] Rogers WJ. Sterilisation of Polymer Healthcare Products. Shrewsbury, UK: Smithers Rapra Press; 2005. p. 336

Chapter 5

Simulation of Ozone Gas Absorption Cross-Section: A Concentration-Based Analysis for Green Communication

Michael David, Mohd Haniff Ibrahim, Sevia Mahdaliza Idrus and Tay Ching En Marcus

Abstract

This chapter explores the impact of ozone concentration on its absorption cross section in the visible spectrum. We used a computer program called Spectralcalc.com and a database of ozone absorption lines (HITRAN 2012 line list) to simulate how ozone absorption cross-section changes with different concentrations. While transmittance through a 50 cm gas cell exhibited a continuous dependence on concentration, the absorption cross section of 5.1055×10^{-25}m2 /molecule itself remained constant for wavelengths around 603 nm at concentrations of 170 ppm and above. This finding deviates slightly (between 1.41 and 2.44%) from previous studies. Our simulations suggest that ozone concentrations between 170 and 1200 ppm have a negligible effect on the absorption cross section at this specific wavelength.

Keywords: absorption cross section, concentration, ozone gas, transmittance, visible spectrum

1. Introduction

Ozone (O_3), a triatomic molecule composed of three oxygen atoms, plays a dual role in Earth's atmospheric chemistry. While it is essential for shielding life from harmful UV radiation in the stratosphere, it is considered a pollutant when found in the troposphere.

1.1 Ozone in the stratosphere: A protective shield

The authors have previously underscored the importance of ozone gas and the effectiveness of optical absorption spectroscopy as a technique for its quantification [1, 2]. UV radiation absorption: Stratospheric ozone absorbs UV-B and

UV-C radiation, preventing these harmful rays from reaching the Earth's surface. Overexposure to UV radiation can cause skin cancer, cataracts, and damage to plants.

Natural formation: Ozone is naturally produced in the stratosphere through chemical reactions involving oxygen molecules and sunlight.

Ozone hole: Human activities, particularly the release of chlorofluorocarbons (CFCs) and other ozone-depleting substances, have led to the formation of the ozone hole over Antarctica. International efforts to phase out these substances have helped to mitigate ozone depletion.

1.2 Ozone in the troposphere: A pollutant

Ground-level ozone: Tropospheric ozone is often referred to as ground-level ozone. It is a secondary pollutant, formed from chemical reactions between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight.

Health and environmental impacts: Ground-level ozone can irritate the respiratory system, causing coughing, wheezing, and chest pain. It can also damage plants and accelerate the deterioration of materials.

Air quality concerns: High levels of ground-level ozone contribute to air pollution and can negatively impact human health and ecosystems. Ozone is a complex molecule with both beneficial and harmful effects. Its presence in the stratosphere is crucial for protecting life on Earth, while its accumulation in the troposphere poses significant health and environmental risks.

1.3 Optical absorption spectroscopy: A precise tool for ozone measurement

Optical absorption spectroscopy is a powerful analytical technique that has found widespread application in various scientific fields, including atmospheric chemistry. This method is particularly well-suited for measuring the concentration of ozone gas, a critical component of the Earth's atmosphere.

1.4 The principle of optical absorption spectroscopy

Light absorption: When a light beam passes through a gas sample, certain wavelengths of light can be absorbed by the molecules present in the gas. The amount of light absorbed depends on the concentration of the absorbing species.

Ozone absorption: Ozone molecules absorb specific wavelengths of ultraviolet (UV) light. By measuring the amount of UV light absorbed by a gas sample, scientists can infer the concentration of ozone present.

Beer-Lambert law: The relationship between light absorption and concentration is described by the Beer-Lambert law, which states that the absorbance of a solution is directly proportional to the concentration of the absorbing species and the path length of the light beam.

1.4.1 Applications of optical absorption spectroscopy in ozone measurement

Atmospheric monitoring: Optical absorption spectroscopy is a key tool for monitoring ozone concentrations in the atmosphere, particularly in the stratosphere where ozone plays a crucial role in protecting the Earth from harmful UV radiation.

1.4.2 Advantages of optical absorption spectroscopy

High sensitivity: Optical absorption spectroscopy can detect very low concentrations of ozone, making it suitable for a wide range of applications.

Specificity: The technique is highly specific to ozone, allowing for accurate measurements even in the presence of other gases.

Real-time analysis: Optical absorption spectrometers can provide real-time measurements of ozone concentrations, enabling rapid response to changes in atmospheric conditions.

Optical absorption spectroscopy is a reliable and precise method for measuring ozone gas concentrations. Its versatility, sensitivity, and specificity make it an indispensable tool for atmospheric research and environmental monitoring.

1.5 Inconsistencies in ozone absorption data: A challenge for accurate measurements

Given the substantial variability and disagreement observed in published ozone absorption data [3], a thorough examination of ozone gas absorption cross-sections is essential to advance our understanding of atmospheric processes and climate modeling.

1.5.1 Sources of inconsistencies

Experimental errors: Factors such as variations in temperature, pressure, and light source intensity can introduce errors in ozone absorption measurements.

Data processing: Differences in data processing techniques, including baseline correction and peak fitting, can lead to variations in calculated ozone concentrations.

Instrument calibration: Inaccurate calibration of spectrometers can result in systematic errors in ozone measurements.

Interference from other gases: The presence of other gases, such as water vapor and carbon dioxide, can interfere with ozone absorption and introduce uncertainties.

1.5.2 The impact of inconsistencies

Atmospheric modeling: Inaccurate ozone measurements can lead to errors in atmospheric models, which are used to predict future climate conditions and air quality.

Policy decisions: Policy decisions related to ozone-depleting substances and air pollution control rely on accurate ozone measurements.

Scientific research: Inconsistencies in ozone data can hinder scientific progress in understanding the chemistry and dynamics of the atmosphere.

Addressing Inconsistencies: The importance of rigorous investigations.

To address the issue of inconsistencies in ozone absorption data, it is essential to conduct rigorous investigations into the factors that influence ozone absorption cross sections. These investigations should involve:

Intercomparison studies: Comparing measurements from different instruments and laboratories to identify sources of discrepancies.

Experimental refinements: Improving experimental techniques to minimize errors and uncertainties.

Data quality control: Implementing strict quality control measures to ensure the reliability of ozone absorption data.

Theoretical modeling: Developing accurate theoretical models of ozone absorption to aid in data interpretation.

1.6 Previous research on window size filter effects

In previous studies, the authors explored the impact of window size filters on ozone gas absorption cross sections [4]. These filters, used to control the flow of gases, can introduce variations in the measurement process. By understanding the effects of window size filters, researchers can optimize experimental setups and improve the accuracy of ozone measurements.

1.7 Challenges in ozone concentration control

One of the challenges encountered in previous studies was fluctuations in ozone gas concentration, even at constant flow rates [4]. These fluctuations can arise from various factors, including variations in the oxygen and ozone gas sources, mixing inefficiencies, and potential nonlinear effects at high ozone concentrations.

1.7.1 Nonlinearity of Beer-Lambert law at high concentrations

At high ozone concentrations, particularly near saturation points, the Beer-Lambert law, which forms the basis of optical absorption spectroscopy, may exhibit nonlinear behavior [5–7]. This nonlinearity can introduce errors in ozone concentration measurements, further emphasizing the importance of understanding the effects of ozone concentration on absorption cross sections.

The need to investigate concentration variation.

The potential influence of ozone concentration on absorption cross sections is a critical factor that must be thoroughly investigated to ensure accurate ozone measurements and atmospheric modeling. Understanding these relationships will enable researchers to:

1.7.2 Refine measurement techniques

- Optimize spectrometer settings: By understanding how concentration affects absorption, scientists can adjust spectrometer settings to achieve optimal sensitivity and accuracy over a wide range of ozone concentrations.

- Correct for concentration-dependent errors: Identifying and quantifying concentration-dependent errors can lead to the development of correction factors that can be applied to improve the accuracy of ozone measurements.

- Develop new measurement methods: The insights gained from studying concentration effects may lead to the development of novel measurement techniques that are less susceptible to concentration-dependent biases.

1.7.3 Improve atmospheric models

- Enhance model accuracy: Incorporating accurate representations of concentration-dependent absorption cross sections into atmospheric models will improve their ability to simulate ozone distribution and transport.

- Predict ozone trends: More accurate models can provide better predictions of future ozone trends, aiding in the development of effective air quality management strategies.

2. Simulation software and methodology

2.1 Platform

Spectralcalc.com: An online platform for high-resolution spectral modeling was chosen. Spectralcalc offers user-friendly interfaces and pre-loaded databases for various spectroscopic tasks.

2.2 Spectral database

HITRAN 2012 line list: This specific database was employed. HITRAN (HIgh-Resolution TRANsmission) is a widely recognized and comprehensive database containing spectroscopic parameters for various molecules. The 2012 version contains line-by-line data for ozone (and other molecules) that allows for detailed simulations of absorption cross-sections.

2.3 Simulations

2.3.1 Target gas: Ozone (O_3)

Isotopologues: All naturally occurring isotopes of ozone were included in the simulations. This accounts for the slight variations in mass and spectral properties of different ozone isotopes.

2.3.2 Concentration range

Simulations were performed for a range of ozone concentrations: 10 ppm (parts per million) to 1200 ppm.

2.3.3 Temperature range

The simulations investigated the effect of temperature on ozone absorption. The range explored was 297 K (24°C) to 303 K (30°C). This range might be relevant to typical laboratory or atmospheric conditions.

2.3.4 Gas cell path length

A fixed gas cell length of 50 cm was used, see **Figure 1**. This parameter defines the distance light travels through the ozone sample within the cell. The path length significantly influences the overall absorption observed.

2.3.5 Wavelength range

Simulations focused on the visible spectrum, specifically the narrow range of 601.02 nm to 604.02 nm. This selection likely targets the peak absorption region of ozone within the visible range.

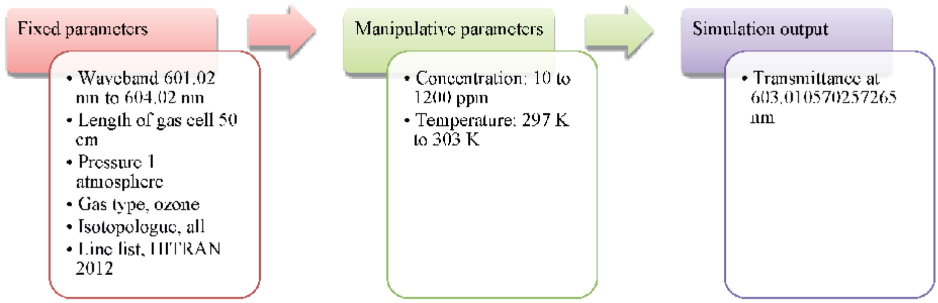


Figure 1.
Methodology: Spectralcalc.com simulation parameters. Source: Author's original work. It was published at the International Science Postgraduate Conference, Universiti Teknologi Malaysia, 2016. Available from: https://www.researchgate.net/publication/295605774_Concentration_Effect_Simulation_On_Ozone_Gas_Absorption_CrossSection [8].

2.3.6 Pressure

A constant pressure of 1 atmosphere (atm) was assumed for the simulations. Pressure can affect gas density and potentially influence absorption properties.

2.3.7 Output

The simulations are expected to provide absorption cross-sectional data centered at 603 nm (precisely 603.0105702572658 nm). Absorption cross section describes how strongly a molecule absorbs light at a particular wavelength.

Justification for this central wavelength is provided from the following referenced literature sources [9, 10]. These references support the claim that ozone exhibits its maximum peak absorption at 603 nm in the visible spectrum.

3. Results and discussion

Figure 2a and **b** illustrates the influence of temperature and ozone concentration on transmittance. As temperature rises, transmittance increases, with this effect becoming more pronounced at higher ozone concentrations. For example, between 297 and 303 K, transmittance rises by 0.00012% at 10 ppm and by 0.01499% at 1200 ppm. Conversely, transmittance generally decreases with increasing ozone concentration, aligning with the Beer-Lambert law [11]. Across all temperatures, an average decrease of 0.75% in transmittance was observed from 10 to 1200 ppm, as summarized in **Table 1**. Ozone gas absorption cross sections and deviations were calculated using Eqs. 1 and 2, previously defined in our earlier publications [4, 12].

3.1 Summary

3.1.1 Temperature effect on transmittance

- As temperature increases, transmittance of ozone gas increases.
- This effect is more pronounced at higher ozone concentrations.

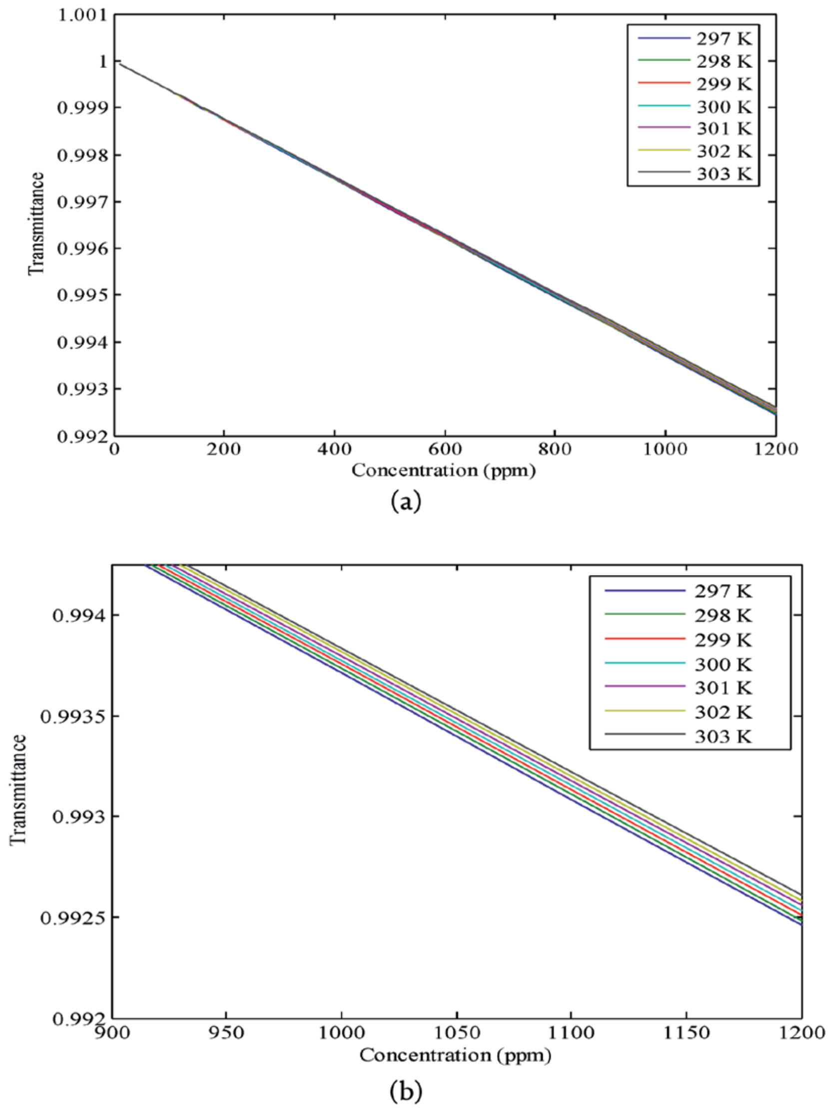


Figure 2.
(a) Transmittance versus concentration for temperatures 297–303 K. (b) Zoom-in effect of transmittance versus concentration for temperature 297–303 K. Source: Author's original work. It was published at the International Science Postgraduate Conference, Universiti Teknologi Malaysia, 2016. Available from: https://www.researchgate.net/publication/295605774_Concentration_Effect_Simulation_On_Ozone_Gas_Absorption_CrossSection [8].

- For example, at 10 ppm, the increase in transmittance between 297 and 303 K is relatively small (0.00012%).
- However, at 1200 ppm, the increase is significantly larger (0.01499%).
- This suggests that temperature has a greater impact on the absorption properties of ozone at higher concentrations.

Temperature (K)	297	298	299	300
Concentration				
10 (ppm)	0.9999369	0.9999371	0.9999373	0.9999376
1200 (ppm)	0.9924591	0.9924843	0.9925094	0.9925342
Temperature (K)	**301**	**302**	**303**	
Concentration				
10 (ppm)	0.9999378	0.9999380	0.9999382	
1200 (ppm)	0.9925589	0.9925835	0.9926079	

Source: Author's original work. It was published at the International Science Postgraduate Conference, Universiti Teknologi Malaysia, 2016. Available from: https://www.researchgate.net/publication/295605774_Concentration_Effect_Simulation_On_Ozone_Gas_Absorption_CrossSection [8].

Table 1.
The variation of transmittance with temperature and concentration of ozone.

3.1.2 Ozone concentration effect on transmittance

- In general, transmittance decreases as ozone concentration increases.
- This observation aligns with the Beer-Lambert law, which states that the absorbance of a substance is directly proportional to its concentration.
- Across all temperatures studied, an average decrease of 0.75% in transmittance was observed when increasing ozone concentration from 10 to 1200 ppm.

3.1.3 Calculations

- Ozone gas absorption cross sections: These were calculated using Eqs. (1) and (2).
- Deviations: These were calculated to quantify the variability or uncertainty in the measured or calculated absorption cross sections.

Eqs. (1) and (2) used to calculate ozone gas absorption cross sections have been previously defined by the authors in Refs. [4, 12].

$$\sigma = -\frac{10^6 \times R \times T_p}{c_{(ppm)} \times N_A \times P \times L} \times \ln T \qquad (1)$$

Where:
$c_{(ppm)}$ = Concentration of ozone in ppm
R = Ideal gas constant (atm m^3 mol^{-1} K^{-1})
T_p = temperature (K)
σ = Absorption cross section (m^2 / molecules)
N_A = Avogadro's constant ((molecule/mol))
P = Atmospheric pressure (atm)
L = Optical path length (m)
T = Transmittance

$$\frac{\sigma - \sigma_w}{\sigma_w} \times 100\% \tag{2}$$

(Where) σ = ozone absorption cross section of previous work at wavelength 603 nm
σ_w = ozone absorption cross section of this simulation at wavelength 603 nm

Figures 3 and **4** illustrate the impact of varying ozone concentrations on the absorption cross section. As shown, the effects at different temperatures overlap. The absorption cross section initially rises from 10 ppm, reaches a peak, and then abruptly

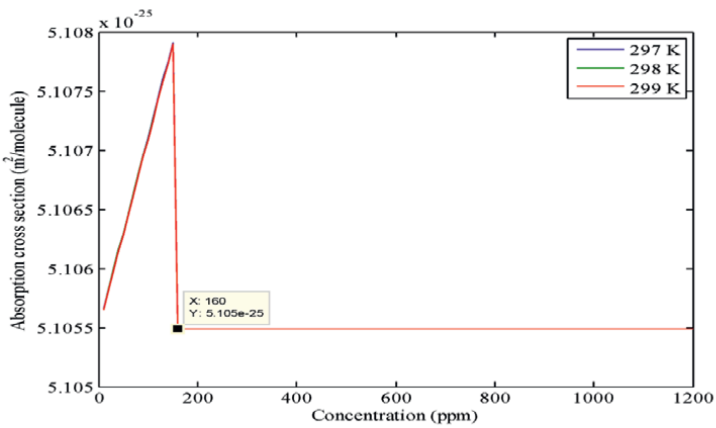


Figure 3.
Simulated absorption cross section for temperature 297–299 K. Source: Author's original work. It was published at the International Science Postgraduate Conference, Universiti Teknologi Malaysia, 2016. Available from: https://www.researchgate.net/publication/295605774_Concentration_Effect_Simulation_On_Ozone_Gas_Absorption_CrossSection [8].

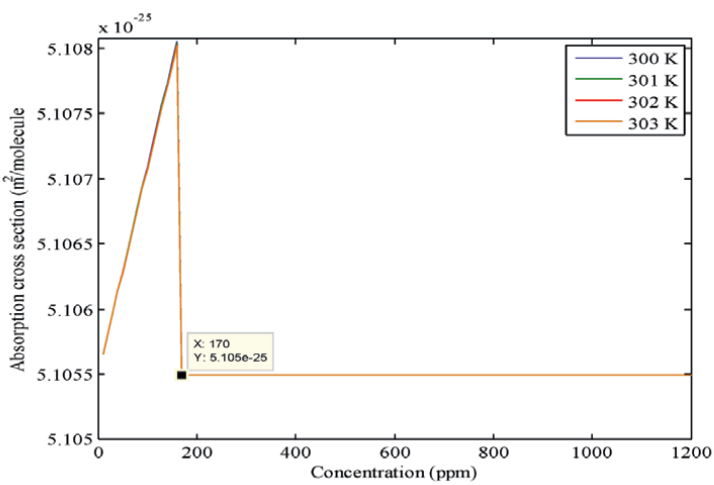


Figure 4.
Simulated absorption cross section for 300–303 K. Source: Author's original work. It was published at the International Science Postgraduate Conference, Universiti Teknologi Malaysia, 2016. Available from: https://www.researchgate.net/publication/295605774_Concentration_Effect_Simulation_On_Ozone_Gas_Absorption_CrossSection [8].

declines to a constant level. This sudden rise and fall occur below 160 ppm for temperatures between 297 and 299 K and below 170 ppm for temperatures between 300 and 303 K. Due to the lower absorption cross section in the visible spectrum compared to the ultraviolet spectrum [10, 13, 14], ozone sensors in the visible range typically exhibit lower sensitivity [10]. Consequently, ozone measurement in the visible spectrum is often recommended for high-concentration industrial applications. The findings of this study indicate that concentration variations have a negligible effect on the absorption cross section for ozone concentrations of 170 ppm and above.

3.2 Summary

3.2.1 Key findings

- Effect of ozone concentration:
  - **Figures 3** and **4** demonstrate how varying ozone concentrations influence the absorption cross section in the visible spectrum.
  - The absorption cross section initially increases from 10 ppm, reaches a peak, and then abruptly decreases to a constant level.
  - This pattern suggests that the absorption behavior of ozone is not linear with concentration, especially at lower concentrations.
- Temperature influence:
  - The effect of temperature on the absorption cross section is relatively small and overlaps within the studied range (297–303 K).
  - The peak concentration where the absorption cross-sectional changes abruptly occurs at slightly different values for different temperatures:
    - Below 160 ppm for 297 and 299 K.
    - Below 170 ppm for 300 and 303 K.
  - Comparison to ultraviolet spectrum:
  - The absorption cross section in the visible spectrum is generally lower than in the ultraviolet spectrum.
  - This difference in absorption strength has implications for ozone sensor sensitivity.
- Implications for ozone sensors:
  - Ozone sensors operating in the visible range typically exhibit lower sensitivity due to the weaker absorption of ozone in this region.
  - For high-concentration industrial applications, ozone measurement in the visible spectrum might be less suitable.

- The results suggest that for ozone concentrations above 170 ppm, concentration variations have a negligible effect on the absorption cross section. This could be relevant for applications where precise measurements are needed at high ozone levels.

Averaged absorption cross sections for all temperatures at a concentration of 10 ppm were calculated to be approximately $5.1057\times10^{-25}\,m^2$ / molecule. The peak point exhibited an absorption cross section of approximately $5.1080\times10^{-25}\,m^2$ / molecule, while the constant level displayed an average absorption cross section of $5.1055\times10^{-25}\,m^2$ / molecule. Compared to the value of $5.18\times10^{-25}\,m^2$ / molecule at 603 nm [10, 15], percentage deviations ranged from 1.41% (at the peak points) to 1.46% (at the constant points), with a difference of 0.05%. Similarly, compared with $5.23\times10^{-25}\,m^2$ / molecule at 603 nm [9], percentage deviations fell within the range of 2.39–2.44%, again with a difference of 0.05%.

3.3 Summary

- Averaged absorption cross sections:
  - The average absorption cross sections for all temperatures at a concentration of 10 ppm were calculated and found to be approximately [insert specific values].
  - The maximum point exhibited a slightly higher absorption cross section compared to the constant level.
- Comparison to Literature Values:
  - The calculated absorption cross sections were compared to reference values at 603 nm [9, 10, 15].
  - Percentage deviations were calculated to assess the agreement between the experimental and literature values.
- Deviation analysis:
  - The percentage deviations ranged from 1.41 to 1.46% compared to the reference value from [10, 15], with a difference of 0.05%.
  - Similarly, deviations ranged from 2.39 to 2.44% compared to the reference value from [9], again with a difference of 0.05%.
- Implications:
  - The relatively small percentage deviations suggest that the calculated absorption cross-sections are in reasonable agreement with the literature values.
  - This agreement provides confidence in the accuracy of the experimental measurements and data analysis.
  - The slight differences between the calculated and literature values could be attributed to factors such as experimental uncertainties, variations in measurement conditions, or differences in the specific ozone isotopologues considered in the simulations.

4. Relevance of findings on green communication

The findings of this research on ozone gas absorption hold significant potential for both direct and indirect contributions to green communication efforts.

4.1 Direct relevance

- Enhanced environmental monitoring and regulation:
    - This research can lead to the development of cost-effective, efficient ozone monitoring networks. These networks can provide real-time data on ozone levels in urban areas and industrial zones, enabling targeted emission control strategies.
    - Improved measurement accuracy can lead to more stringent and effective ozone regulations. For instance, stricter emission standards for vehicles and industries might be implemented based on precise ozone data.
- Green technology development and implementation:
    - Understanding ozone behavior can inform the design of green technologies with minimal environmental impact. For example:
        - Air filtration systems in buildings can be optimized to effectively remove ozone alongside other pollutants.
        - Renewable energy sources, like solar panels, may benefit from coatings that minimize ozone degradation and enhance efficiency.
        - The development of "ozone-friendly" refrigerants can be accelerated based on a deeper understanding of ozone interactions with various materials.

4.2 Indirect relevance

- Climate change mitigation strategies:
    - Improved knowledge of ozone absorption can contribute to climate models. These models can better predict the interplay between ozone, greenhouse gases, and overall climate change.
    - By understanding how ozone interacts with other atmospheric components, researchers can develop strategies to mitigate climate change, potentially leading to initiatives such as ozone-friendly agricultural practices that minimize ground-level ozone production.
- Public health and environmental protection:
    - Accurate ozone data enable targeted public health advisories during periods of high ozone concentration, prompting individuals to limit outdoor activity and protect vulnerable populations.

- Precise ozone monitoring allows for regulations aimed at reducing harmful ozone precursors, such as nitrogen oxides, leading to cleaner air and improved public health.

- Understanding ozone interactions with ecosystems can inform conservation efforts and the development of strategies to protect plant and animal life from detrimental ozone exposure.

4.3 Overall contribution to green communication

The findings of this research not only improve our understanding of ozone but also pave the way for the development of environmentally friendly technologies and practices. This aligns directly with the core principles of green communication, which promotes open communication and collaboration toward a sustainable future. By fostering knowledge exchange on ozone behavior and its impact on the environment, this research can empower individuals and organizations to make informed decisions that minimize their environmental footprint and contribute to a cleaner, healthier planet.

5. Conclusion and recommendations

This study examined the impact of varying ozone concentrations on transmittance and absorption cross section across different temperatures. Within the temperature range of 297–303 K, transmittance increased by 0.00012% at 10 ppm and by 0.01499% at 1200 ppm. However, a general decrease of 0.75% in transmittance was observed from 10 ppm to 1200 ppm at constant temperatures. Comparing the absorption cross section at the peak points (approximately $5.1080 \times 10^{-25}\, m^2 / molecule$) to the constant level (approximately $5.1055 \times 10^{-25}\, m^2 / molecule$), a percentage deviation of 0.05% was found. Ozone gas absorption cross-sectional deviations ranged between 1.41 and 2.44% compared to previous studies. The results of this study indicate that concentration variations have a negligible effect on the absorption cross section for ozone concentrations of 170 ppm and above. Consequently, future research on absorption cross sections in the visible spectrum can disregard the impact of concentration for concentration values of 170 ppm and above.

5.1 Summary

- Temperature and concentration effects on transmittance:
  - Temperature increases led to slight increases in transmittance, especially at higher ozone concentrations.
  - Increasing ozone concentration generally decreased transmittance, aligning with the Beer-Lambert law.
- Absorption cross-sectional analysis:
  - The absorption cross section exhibited a nonlinear relationship with concentration, with a peak followed by a sudden decrease.

- Temperature variations had a relatively small impact on the absorption cross section.
- Deviations between calculated and literature values were within acceptable limits, indicating the accuracy of the measurements.

- Implications for ozone measurement:
    - For ozone concentrations above 170 ppm, concentration variations can be disregarded in future studies of absorption cross sections in the visible spectrum.
    - This simplifies the analysis and modeling of ozone gas absorption in certain applications.

- Environmental significance:
    - Ozone plays a vital role in the Earth's atmosphere, protecting it from harmful ultraviolet radiation.
    - Excessive ozone levels in the troposphere, however, can contribute to air pollution and have negative health impacts.

- Green communications and ozone measurement:
    - Accurate measurement of ozone gas is crucial for environmental monitoring and regulation.
    - This research contributes to the development of technologies and practices that aim to minimize environmental impact (green communications).
    - By enhancing ozone gas measurement and regulation, this study indirectly supports efforts to reduce ozone emissions and improve air quality.

5.2 Recommendations

5.2.1 Expanding the recommendations

5.2.1.1 Recommendation 1: Further experimental studies

- Controlled experiments: Conduct experiments under a wider range of conditions, including varying pressure, humidity, temperature, and ozone concentrations. This will help to establish the generalizability of the findings and identify any potential limitations.

- Comparison with other techniques: Compare the results obtained using the proposed method with those from established ozone measurement techniques, such as chemiluminescence and UV absorption spectroscopy. This will help to validate the accuracy and reliability of the new method.

- Investigation of interferences: Study the effects of other gases, such as water vapor, carbon dioxide, and hydrocarbons, on ozone absorption in the visible spectrum. This will help to assess the selectivity of the proposed method and identify potential sources of interference.

5.2.1.2 Recommendation 2: Applications in high-concentration environments

- Industrial processes: Explore the potential applications of the proposed method in industrial processes where high concentrations of ozone are encountered, such as wastewater treatment, air purification, and materials processing.

- Environmental monitoring: Investigate the feasibility of using the method for real-time monitoring of ozone concentrations in polluted environments, such as urban areas and industrial complexes.

- Safety and health: Develop portable devices or sensors based on the proposed method for personal safety and health monitoring in environments with high ozone levels.

5.2.1.3 Overall contributions

- Advancement of ozone measurement: The research contributes to the development of more accurate and reliable ozone measurement methods, which have significant implications for air quality monitoring, environmental protection, and human health.

- Understanding of ozone behavior: The study provides valuable insights into the behavior of ozone gas absorption in the visible spectrum, expanding our knowledge of this important atmospheric constituent.

- Potential for new applications: The findings of the research may lead to the development of new applications for ozone measurement in various fields, such as environmental science, industrial processes, and personal safety.

Acknowledgements

Universiti Teknologi Malaysia (UTM):

- The authors express their sincere gratitude to UTM for the financial support provided through the Research University Grant (RUG) Scheme.

- The grants 05 J60 and 04H35 were instrumental in funding this research project.

Ministry of Higher Education (MOHE) Malaysia:

- The authors acknowledge the generous funding provided by MOHE Malaysia through the Fundamental Research Grant Scheme (FRGS).

- The grants 4F317 and 4F565 contributed significantly to the successful completion of this research.

Nigerian Education Trust Fund (ETF):

- The authors thank the ETF for the financial support provided through the Tertiary Education Trust Fund (TET-Fund).
- This funding was essential for conducting the research and supporting the researchers involved.

Author details

Michael David[1*], Mohd Haniff Ibrahim[2], Sevia Mahdaliza Idrus[2] and Tay Ching En Marcus[3]

1 Department of Telecommunication Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Nigeria

2 Department of Communication Engineering, Faculty of Electrical Engineering, Lightwave Communication Research Group, Innovative Engineering Research Alliance, Universiti Teknologi Malaysia, Johor, Malaysia

3 Faculty of Engineering and Computing, Sungai Buloh, Malaysia

*Address all correspondence to: mikeforheaven@futminna.edu.ng

IntechOpen

© 2024 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] David M, Ibrahim MH, Idrus SM, Azmi AI, Ngajikin NH, Marcus TCE, et al. Progress in ozone sensors performance: A review. Jurnal Teknologi. 2015;**73**(6):22-23

[2] David M, Ibrahim MH, Idrus SM, Marcus TCE. Fundamental review to ozone gas sensing using opticals fibre sensors. TELKOMNIKA (Telecommunication Computing Electronics and Control). 2015;**13**(4):1133-1144

[3] Serdyuchenko A, Gorshelev V, Weber M, Chehade W, Burrows J. High spectral resolution ozone absorption cross-sections–part 2: Temperature dependence. Atmospheric Measurement Techniques. 2014;**7**:625-636

[4] David M, Ibrahim MH, Idrus SM. Sampling frequency effect on the absorption cross section of ozone in the visible Spectrum. Journal of Optoelectronics and Advanced Materials. 2015;**17**:403-408

[5] Marcus TC, David M, Yaacob M, Salim MR, Hussin N, Ibrahim MH, et al. Alternative wavelength for linearity preservation of Beer-Lambert Law in ozone concentration measurement. Microwave and Optical Technology Letters. 2015;**57**:1013-1016

[6] Fuwa K, Valle B. The physical basis of analytical atomic absorption spectrometry. The pertinence of the Beer-Lambert law. Analytical Chemistry. 1963;**35**:942-946

[7] Yasin M, Harun S, Tan C, Phang S, Ahmad H. Fiber optic chemical sensor using fiber coupler probe based on intensity modulation for alcohol detection. Microwave and Optical Technology Letters. 2011;**53**:1935-1938

[8] David M, Ibrahim MH, Idrus SM, Marcus TCE. Concentration effect simulation on ozone gas absorption cross section. In: 4th International Science Postgraduate Conference 2016; Johor Bahru Malaysia. Malaysia: Universiti Teknologi Malaysia; 2016. pp. 1-7

[9] Brion J, Chakir A, Charbonnier J, Daumont D, Parisse C, Malicet J. Absorption spectra measurements for the ozone molecule in the 350-830 nm region. Journal of Atmospheric Chemistry. 1998;**30**:291-299

[10] O'Keeffe S, Fitzpatrick C, Lewis E. An optical fibre based ultra violet and visible absorption spectroscopy system for ozone concentration monitoring. Sensors and Actuators B: Chemical. 2007;**125**:372-378

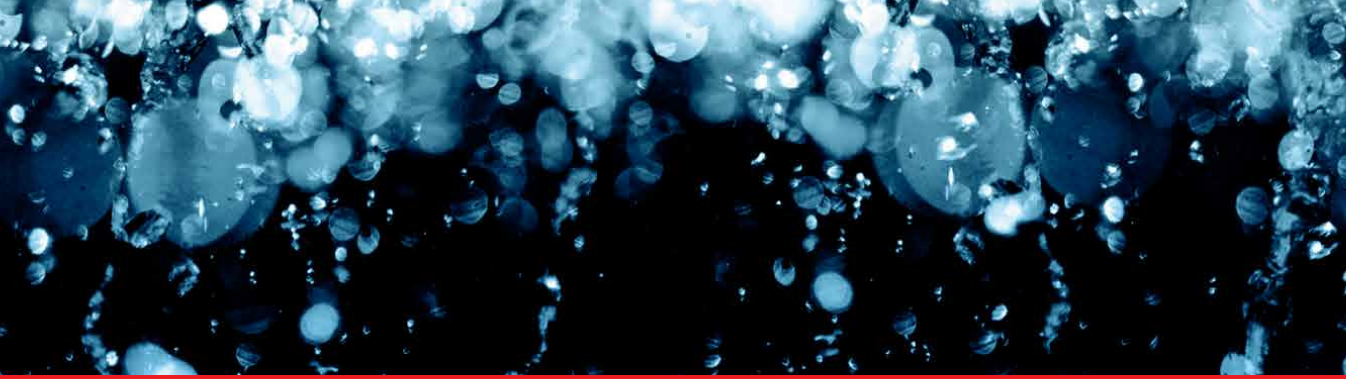
[11] Denney RC. Dictionary of Spectroscopy. 2nd ed. New York: Willey; 1982. pp. 119-120

[12] Marcus TCE, David M, Yaacob M, Salim MR, Hussin N, Ibrahim MH, et al. Pressure dependence of ozone absorption cross section. Applied Mechanics and Materials. Trans Tech Publications. 2015;**735**:260-264

[13] Teranishi K, Shimada Y, Shimomura N, Itoh H. Investigation of ozone concentration measurement by visible photo absorption method. Ozone: Science and Engineering. 2013;**35**:229-239

[14] Orphal J. A critical review of the absorption cross-sections of O_3 and NO_2 in the ultraviolet and visible. Journal of Photochemistry and Photobiology A: Chemistry. 2003;**157**:185-209

[15] Vigroux E. Contribution à l'étude expérimentale de l'absorption de l'ozone, par Ernest. Vigroux: Masson; 1953



Edited by Murat Eyvaz, Ahmed Albahnasawi, Ercan Gürbulak and Ebubekir Yüksel

Water pollution is one of the most critical environmental issues of our time, driving the need for advanced and sustainable solutions. Among the various treatment technologies available, ozonation has emerged as a powerful and versatile tool for addressing water quality challenges. *Ozonation - New Aspects* offers a deep dive into the latest research, innovations, and applications of this technology, highlighting its potential to transform the field of water and wastewater treatment. This book brings together a collection of expert contributions, each exploring a different side of ozonation technology. From fundamental principles and chemical reactions to industrial applications and hybrid processes, the chapters provide comprehensive insights into the benefits, challenges, and future directions of ozonation. Readers will find valuable discussions on topics such as the treatment of complex organic pollutants, the role of ozonation in textile effluent management, and the optimization of ozone dosage for industrial settings. With its detailed analysis and practical case studies, *Ozonation - New Aspects* is an essential resource for researchers, engineers, and practitioners in the field of environmental science and water treatment. Whether you are looking to enhance your understanding of advanced oxidation processes or seeking innovative approaches to solving water pollution issues, this book offers the knowledge and tools necessary to drive progress toward cleaner, safer water systems.

Published in London, UK
© 2024 IntechOpen
© naratrip boonroung / iStock

IntechOpen

ISBN 978-1-83768-930-9