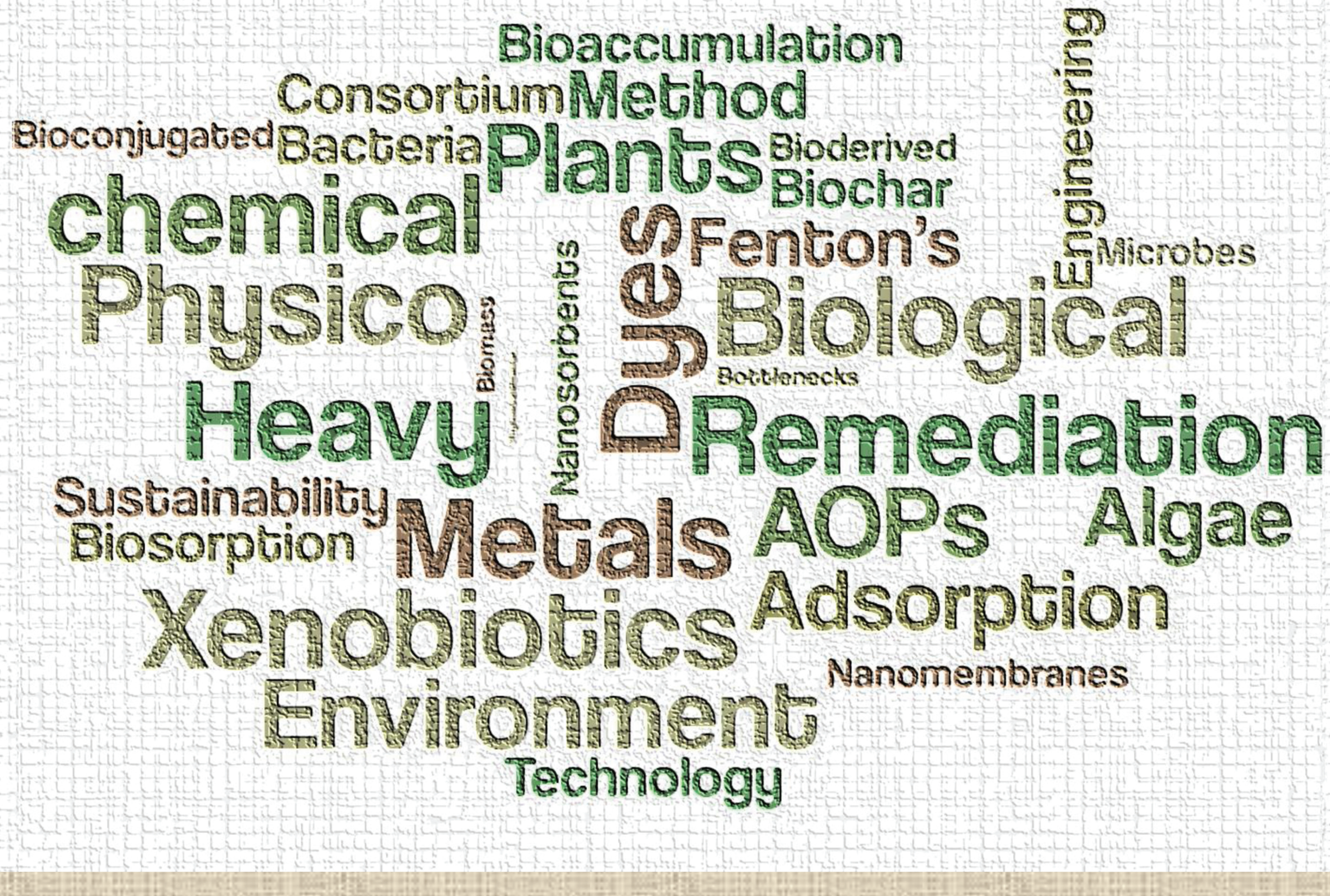
# RECENT TRENDS AND INNOVATIONS IN SUSTAINABLE TREATMENT TECHNOLOGIES FOR HEAVY METALS, DYES AND OTHER XENOBIOTICS



Editors:

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# Recent Trends and Innovations in Sustainable Treatment: Technologies for Heavy Metals, Dyes and Other Xenobiotics

Edited by

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# Recent Trends and Innovations in Sustainable Treatment Technologies for Heavy Metals, Dyes and Other Xenobiotics

Editors: Biswanath Bhunia & Muthusivaramapandian Muthuraj

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# FOREWORD

Over the decades, the environment and sustainable development have become major alarms in the engineering industry. The goal of environmental engineering is to ensure that societal development and the use of all resources such as water, land, and air are sustainable. In other words, environmental engineering can ensure the protection of the environment and understand and improve the interactions between human beings and natural environments. The effort to make such challenges effective and economically viable involves substantial interaction among chemical engineers, biochemical engineers, biotechnologists, biochemists, microbiologists, and geneticists. Environmental engineers are mainly associated with water, soil and air pollution problems, and develop technical solutions needed to solve, attenuate or control these problems in a manner that is compatible with legislative, economic, social, and political concerns. Chemical and civil engineers are particularly involved in such activities as water supply and sewerage, management of surface water and groundwater quality, remediation of contaminated sites, and solid waste management. Over the past few decades, biological scientists have produced vast amounts of quantitative information. The life sciences are now seeking a unified basis, with exact knowledge replacing the descriptive approach. Many biological phenomena are now understood and can be employed for the benefit of mankind. While in many cases it has been possible to achieve spectacular reductions in microbiological treatment costs, the risk involved in starting a microbiological venture has never been small, primarily due to a lack of knowledge and talents. Once the problem is recognized for what it is, a realistic solution may be seen which lies in breaking down barriers to communication. This will attract new talents to contribute to environmental engineering research and thereby help advance biotechnology.

This book is a multi-author book concerned with the engineering aspects of environmental science. It is intended to serve the established professionals and also to encourage students to take up careers in this field. The text is organized into areas important to environmental engineers who are working in the field of Sustainable Treatment Technologies for heavy metals, dyes, and other xenobiotics. Any text on environmental engineering is somewhat dated by the time of publication, because the field is moving and changing rapidly. Authors have included those fundamental topics and principles on which the practice of environmental engineering is grounded, illustrating them with contemporary examples. Additionally, chapters on bottlenecks in sustainable treatment of wastewaters using physicochemical processes and future prospects are included. Furthermore, the topic on sustainable mitigation of wastewater issues using microbes: hurdles and future strategies is also included. The analysis of bioprocesses as well as chemical processes has been given prominence in this book. The book deals with some hitherto neglected areas such as sustainable treatment technologies of heavy metals, dyes, and xenobiotics. It is expected that these contributions will stimulate many more talents to contribute through basic research and dissemination of knowledge to the "yet to emerge" hybrid discipline of environmental engineering.

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# PREFACE

Industrial inflations and demographic expansions resulted in incessant pollution of water resources with hazardous chemicals and complex xenobiotic compounds that challenge environmental sustainability. With the high cost and high energy requirements, complex plant designs, less efficiency in recovery, the conventional wastewater treatment strategies fail to support a feasible large-scale process resulting in the release of untreated wastewater into the environment. These serious concerns must be addressed with a feasible and sustainable technology that can remediate contaminated wastewater with scope for reutilization and recycling. Over the past decade, the research in this field keeps producing new processes and techniques to overcome the deficiencies encountered in these technologies. Several innovative green technologies are being outlined to address these issues with environmental sustainability and wastewater treatment such as nano-sized membrane-based treatment strategies, microalgae-based pollution management, commercial-scale fuel cells, inverse fluidization technology, *etc*. However, commercial-scale feasibility and applicability of these technologies are still far from realization. The present book 'Recent Trends and Innovations in Sustainable Wastewater Treatment Technologies' aims to address all these issues by integrating the knowledge of innovation technologies that have been developed predominantly in the past decade and the available commercial-scale processes altogether to understand the path ahead in reaching sustainability and high efficiency in wastewater treatment.

The book has been compiled into eight chapters. Chapter 1 details the various types of prevailing wastewater, its characteristics, and the major commercial-scale strategies employed to treat those types of wastewater. Chapter 2 details predominantly the different types of physicochemical methods utilized for the remediation of heavy metals, dyes, and xenobiotics. Chapters 3 and 4 highlight the innovations in the advanced oxidation process and adsorption for remediation of such complex molecules respectively. Chapters 6, and 7 individually address the recent innovations in the bioremediation of heavy metals, and dyes respectively. Finally, chapters 8 and 9 discuss the latest technologies, prevailing bottlenecks, and the path ahead towards commercial viability and environmental sustainability in both physicochemical and biological treatment processes.

We are obliged to the authors for their contributions and to the reviewers for their comprehensive comments on shaping up the chapters and improving their quality.

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## CHAPTER 1

# Wastewater Types, Characteristics and Treatment Strategies

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**Abstract:** One of the most important issues in recent times is the remediation of wastewater discharged from different industries. Several of the growing economies have been investing heavily to reduce the discharged waste content for economic and environmental sustainability. The wastewater when discharged into natural water bodies harms the flora and fauna of the surrounding environment, which in turn disrupts the ecosystem and affects the food chain. It also increases and possesses a variety of health risks to human beings. To eliminate the potential threats, a critical analysis of the past research and upcoming remediation technologies is necessary. Over the years, a lot of advancements have been made to curb the disruption of the natural ecology from effluent discharges by different industries like the leather industry wastewater, Rice mill wastewater, pharmaceutical industry wastewater and Coke Oven wastewater. The common characterization techniques that are employed in all of them are to measure the COD and BOD levels, pH, odor, TSS, organic and inorganic materials. Subsequently, the common technologies that are in use to treat these wastewaters are mainly physicochemical treatments like adsorption, electro-coagulation/flocculation, nanofiltration, Fenton's oxidation or biological treatments like aerobic/anaerobic microbial degradation. An important requirement is to understand the situation currently prevalent in wastewater treatment to develop better and advanced methods for increased efficiency and waste removal. The aim of this chapter is to give a detailed account on the composition, characterization, and treatment strategies of the discharged effluent to enhance the knowledge of available resources and instigate ideas of future improvements.

**Keywords:** Industries, Treatment, Dyes, Pharmaceuticals, Heavy metals.

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# 1. INTRODUCTION

The world's population is continuously increasing along with rapid industrialization which highlights the environmental concerns that arise from industrial wastes [1]. Industrial waste and pollution have become major contributing factors to the degradation of the environment over the years. It was observed through various investigations that almost half of the medium and small-scale industries contribute greatly to water pollution by waste discharge in natural water bodies [2]. The environmental, economic, and societal implications of waste discharge give rise to unavoidable discord between industrialization and environmental sustainability [3, 4]. Due to the mobile nature, detrimental impacts are observed on biodiversity from effluents if discharged without proper and substantial remediation [5, 6]. Also, nowadays, the discharge is from different industries like chemical, pharmaceutical, leather, textile, *etc*., which influences the characteristics of the discharged wastewater making it difficult to predict the composition. Hence, the treatment of these wastewaters has attracted more investigation to preserve the environment [7].

Tannery industry earns a large amount of foreign exchange through its leather export and is also one of the most important industries in India. After tanning, the effluents released contains high amount of trivalent chromium, BOD and COD levels, NaCl, sulfides, Mg, Ca, organics, and other toxic ingredients. These effluents affect the natural ecosystem and subsequently possess a variety of health risks to human beings [8, 9]. For example, in Dhapa, Kolkata (India), wastewater from nearby tanneries is disposed of that affects the food chain of human beings [8]. The standard methods of treating tannery wastewater are by adsorption [10, 11], coagulation/flocculation [12], oxidation by Fenton's reagent [13], nanofiltration [14, 15]. Recently, bioremediation technologies are being used by the industries to degrade the generated waste either aerobically or anaerobically [16]. One of the major elements for the toxic hazardousness of the wastewater is chromium [17]. The tanning process using chrome releases about 40% of unutilized Cr salts that are often released through the wastewater, giving rise to serious environment implications [18 - 20]. Exposure to common tannery waste like pentachlorophenol, chromium, and other toxic pollutants increases the risk of ulcer nasal septum perforation, dermatitis, and lung cancer [21, 22].

Rice is the main staple food in India and around the world and its production has a significant role in the world economy. Huge quantities of water are required for the soaking of parboiled rice and thus a significant amount of wastewater is generated from rice production which is approximately 1–1.2 L/kg of paddy [23]. One of the most common concerns is its disposal on land that causes soil contamination and consequently results in surface and groundwater quality degradation [24]. Algal blooms that cause odor problems due to eutrophication and many other adverse effects are the outcomes of discharging untreated effluents into natural water bodies [25, 26]. Rice mill effluent has a pungent odor that is mainly yellowish in color and consists of toxic organic materials along with other impurities. Rice mill wastewater consists of COD elements like cellulose, lignin, phenol, and other humic substances that disrupt the environmental sustainability [27]. The most common technologies that are studied for remediation are physicochemical treatments like adsorption [28] and electrocoagulation [29], microbial treatment [30] and phytoremediation [3].

Human health is becoming a subject of prime importance that is leading to the rapid growth of the pharmaceutical sectors, but at the same time, these industries produce a lot of wastewater effluents that are responsible for the degradation of the environment [31]. Various microbial and toxic elements along with virulent pharmaceutical ingredients (API) are released untreated into natural water bodies. The pollutant load in municipal waste is often increased by the improper disposal of unutilized medicine along with metabolic excretion due to drugs by humans and animals, which in turn could affect the ecology and increase health hazards. Various research works have established that the presence of pharmaceutical compounds in aquatic systems often arise from pharmaceutical manufacturing plants [31 - 35]. Thus it affects the food chain as well as plant and animals [36, 37]. Current techniques employed to treat this wastewater in different industries are biochemical treatment [38 - 40], membrane filtration treatment [41], adsorption treatment [42 - 45] and advanced oxidation process treatment [46 - 51] for the removal of waste from industrial wastewater.

Coke ovens are used extensively in the steel and coal industries. Compounds like phenol and cyanide are released with the coke oven wastewater which affects the entire ecosystem, harming the flora and fauna along with the human respiratory system [52, 53]. Thus, a permissible limit of 0.5 mg/L for phenol and 0.2 mg/L for cyanide has been set by different industries for the industrial effluent according to various environmental organizations (WHO, USEPA, and CPCB, India) [54]. Different waste treatment technologies have been used in recent times that focus more on biofilm or fluidized bed reactors [55 - 58], membrane-based bioreactors [59], granular activated carbon [60], and immobilized spent tea activated carbon [61, 62]. Since there exists several factors like public hazards, economic feasibility of upscaling and complexity of the wastewater, the approach towards treating this water have been changed from incineration or chemical decomposition. Bioremediation has been a popular technique for remediation of phenol and cyanide with some of the major degrading organisms being *Escherichia coli* [63], *Pseudomonas* sp [64, 65], *Acinetobacter* sp., *Bacillus* sp [66, 67], *Serratia odoriferra* MTCC 5700, *etc.* Also, immobilization technique

## CHAPTER 2

# High Gravity Technology for Improving Efficiency of Wastewater Treatment Processes

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**Abstract:** Conventional technologies such as stripping, liquid-liquid extraction, chemical precipitation, adsorption, and the advanced oxidation process among others have been applied for the treatment of wastewater. The imposition of stricter regulations on discharge limits has led to a search for novel technologies to make the conventional wastewater treatment technologies efficient and cost-effective. High gravity technology uses centrifugal force to create artificial gravity which is hundreds of times the terrestrial gravitational force. Equipment working in high gravity environment intensifies the rate of mass transfer, micromixing and allows a higher amount of fluid to flow through the devices. The usefulness of high gravity technology for enhancing the performance of wastewater treatment processes has been discussed.

**Keywords:** Air stripping, HIGEE, Liquid-liquid Extraction, Micromixing, Reactors.

## 1. INTRODUCTION

Industrial activity results in the generation of wastewater. Numerous chemical industries like pesticides, pharmaceuticals, paints and dyes, detergent, petrochemicals *etc.*, [1], contaminate water by releasing feedstock materials, byproducts, solvents, cleaning agents and value-added products. Food industry, mines and ores, iron and steel industry, nuclear industry, pulp and paper industry, dairy industry, and breweries also play a significant role in water pollution [1].

In case of mines and ore recovery plants, the water released will inevitably be contaminated with minerals present in the ores. Wastewater from food industry

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has high concentrations of biological oxygen. In breweries, the values of BOD (biological oxygen demand) and COD (chemical oxygen demand) are in the range of 1000-1500 mg/L and 1800-3000 mg/L respectively [2]. Waste water of iron and steel industry contains gasification products (phenols, cresols, ammonia, benzene *etc.*) and mineral acids [3]. The differences in pollutant characteristics in waste water discharge by industries suggest that different techniques have to be employed to treat the wastewater to reduce the pollutant level below the discharge limit. Some of these techniques are discussed below.

## 2. CONVENTIONAL WASTEWATER TREATMENT PROCESS AND EQUIPMENT

### 2.1. Adsorption

Adsorption is a surface phenomenon where molecules of a solution (known as adsorbate) come in contact with an adsorbent and become attached to its surface [4 - 5]. The reason for this is the physical forces or chemical bonds between the adsorbate and adsorbent molecules. Adsorbents are classified as natural and synthetic. Natural adsorbents are classified as organic and inorganic adsorbents. Organic adsorbents include peat, sawdust, vegetable fibers, straw, feathers, milkweed, *etc.* whereas inorganic adsorbents include ores, clays, clay minerals, volcanic ash [6]. Synthetic adsorbents are made from agricultural products and wastes, industrial wastes, household wastes, sewage sludge and polymeric materials, *etc.* [7]. Activated carbon is one of the most popular adsorbents in industries due to its higher surface area, large porous structure, nonpolar characteristics and economic viability [7]. These have been derived from several agricultural and industrial waste materials.

Most of the adsorbents are in the form of granules or in powder. The removal of pollutant occurs as it diffuses through the waste water onto the surface of the adsorbent. Granular adsorbents are commonly used in fixed bed adsorbers. The design of these adsorbers is based on time required to achieve breakthrough point. A typical breakthrough curve is generally S shaped. But sometimes it may be steep or flat in nature and also distorted in some cases. The bed needs to be regenerated after the breakthrough point is reached. Efficient use of adsorbent bed would increase the breakthrough time, reduce the chemicals required for regeneration and the solid waste generated when the adsorbent bed is disposed and hence reduce the cost [8 - 9].

Adsorbent bed will be efficiently utilized in case of infinitely rapid adsorption process. The breakthrough curve would be a straight vertical line. The mechanism of adsorption, resistance to mass transfer in the solution through which the particle diffuses and the intraparticle resistance dictate the adsorption rate. For a given adsorbate-adsorbent system, the adsorption rate can be increased if the intraparticle resistance is reduced by using small adsorbent particles and it ensures negligible mass transfer resistance [10]. However, decreasing the particle size also reduces the void fraction in the bed. Therefore, when liquid flows down the adsorbent bed under gravity, the minimum particle size that can be used is restricted by the required flow rate. Powdered form of adsorbent can be used as an alternate. It is added directly to the waste water or in the form of slurry. The continuous adsorption process using powdered form can be carried out in stirred tank contactors or can be added as the wastewater flows in a pipeline. In this process, the maximum utility of adsorbent takes place when the adsorbent leaving the equipment is in equilibrium with the solution.

## 2.2. Air Stripping

This process has received considerable attention for removal of substances such as ammonia and VOCs from waste water that have reasonable equilibrium vapor pressure at ambient temperature. Wastewater comes in contact with air in order to remove undesirable substances by the air stream [11]. Common gas-liquid contactors that can be used for this process are bubble column, mechanically agitated tanks, packed tower, plate/tray column, spray towers, venture scrubber [12]. A schematic of these equipment is depicted in Fig. (**1**). Each contactor type has a variety of configurations with numerous possible modifications. Packed bed is widely used for stripping. The equation used to determine the height of a stripping tower is given by

$$Z = NTU\text{x}HTU \quad \textbf{(1)}$$

The height of a transfer unit (*HTU*) is defined as

$$HTU = \frac{v_L}{K_L a} \quad \textbf{(2)}$$

The value of HTU depends on overall liquid mass transfer coefficient ($K_L$), the specific interfacial area ($a$) and the liquid velocity ($v_L$). The height of an air stripping tower can be decreased by increasing $K_L$ and $a$. The magnitude of overall volumetric liquid side mass transfer coefficient, $K_La$ reported for a few gas-liquid contactors [12] is given in the Table **1**. The desired flow rate of air determines the diameter of the air stripping column which is in turn is controlled by flooding considerations. For a given equipment volume, air stripping efficiency would be increased if the magnitude of $K_La$ can be increased and higher air flow can be used.

## CHAPTER 3

# Recent Trends in Advanced Oxidation and Catalytic Processes for Removal of Heavy Metals, Dyes, and Xenobiotics

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**Abstract:** Heavy metals, dyes and xenobiotic compounds are the primary environmental contaminants that are accumulating at higher rates attributed to increased industrialization and uncontrolled release without treatment. These pollutants have also raised serious concerns about life on earth, attributed to their recalcitrance and tenacity in the environment. The treatment strategies currently utilize chemical methods, such as advanced oxidation processes (AOPs) and catalytic processes, whereas biological processes such as adsorption and accumulation are also predominant. However, AOPs and catalytic processes are proven to be the potential methods for heavy metals, dyes, and xenobiotic pollutant remediation in large-scale applications. Identification and synthesis of novel molecules/ materials that can effectively recover and remediate heavy metals, dyes and xenobiotic compounds from wastewater remain one of the key approaches. This chapter highlights the success of AOPs and catalytic processes in the degradation of dyes, pharmaceuticals compounds, and heavy metal ions from different water environments and possible future prospects.

**Keywords:** Advanced oxidation process, Dyes, Fenton process, Heavy metals, Xenobiotics.

## 1. INTRODUCTION

Over 70% of the global land is covered with water, however, only 2.5% of the

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total is freshwater suitable for the survival of life [1]. In the current state of demographic expansion and industrial developments, this 2.5% freshwater will be insufficient to meet the needs of life on earth. In the next 50 years, over 40% of the world-wide population is estimated to suffer from water scarcity. To meet the demands, the reuse of wastewater after remediation remains one of the feasible options. Wastewater recycling and reuse in irrigation and industrial activity may also augment the scope towards the expansion of water resources. However, the quality of treatment can be affected by several parameters, such as source, the way it has been collected, and the treatment strategy employed prior to discharge [2]. Wastewater from different sources comprises water, dissolved solids, and colloidal solids at varying concentrations. In industrial wastewaters, the presence of novel emerging contaminants and known pollutants such as halogenated compounds, polyaromatic hydrocarbons (PAH), heavy metals, dyes, pesticides, xenobiotics, phthalates, halogenated compounds, pharmaceutical compounds, and endocrine disruptors are prominently based on the type of industry. These compounds, on release into the environment, lead to irreversible damage to the living systems and affect the ecological system.

The conventional strategies comprise different physical, chemical, and biological processes [3], and are largely categorized as primary, secondary, and tertiary treatment stages along with a separate pretreatment process. The pretreatment involves the removal of large floating particles, sediments, and heavy solids, such as grits, *etc.* Further, primary treatment involves the removal of grease, oil, and scum based on gravity settling and variations in density. The treated wastewater flows to the secondary treatment process, which principally involves biological degradation. Under certain conditions, the requirement for an additional tertiary treatment becomes necessary to get rid of hazardous microorganisms, or toxic chemical derivatives which were not removed *via* two stages of the treatment process. The tertiary treatment process predominantly involves chlorination, ozonation, adsorption, and filtration-based techniques. Chlorination targets to remove the pathogenic infectious microorganisms from infecting the environment, whereas filtration and ozonation are well known for their high-efficiency removal of pathogens but with high cost and energy requirements. However, such conventional technologies have resulted in increased waste production and salting issues that affect freshwater resources. Even today, a large number of pollutants could be detected in the wastewater treated with conventional treatment technologies, which shows the efficiency of those processes. Thus, the search for a novel, economically feasible and sustainable technique for remediating wastewater without harming the environment continues. Among prevailing several techniques, the use of advanced oxidation processes (AOP) with and without catalysts have gained significant interest attributed to their low-cost requirements, robust nature, and effectiveness in decontaminating organic components, heavy inorganic metals, dyes, and other xenobiotics. The use of AOP and associated techniques have been proven to be efficient in the removal of heavy metals, dyes, xenobiotics, pesticides, herbicides, and organic pollutants from various waste resources, food, textile and tannery industries, and municipal sewage. This chapter targets to consolidate the information on the success story of AOP in treating heavy metals, dyes and xenobiotics with prevailing bottlenecks and prospects.

## 2. ADVANCED OXIDATION PROCESS (AOP)

The utilization of ozone ($O_3$) in the disinfection of drinking water commenced in the year 1906 at the Eon Voyage plant located in France. After that, several plants with this particular facility have been created worldwide [4]. Later, Hoigné and Bader [5] explained the involvement of hydroxyl radicals which are formed during ozonation, in the degradation of various organic contaminants. A similar analysis was executed by Glaze *et al*. [6] in 1987and confirmed the presence of such intermediate that strongly influence the degradation process. Thus, the process involving oxidation of contaminants *via* reactions involving the generation of strong oxidants (intermediates) such as hydroxyl ion radicals ($OH^•$) or sulfate radicals ($SO_4^{2-}$) at ambient conditions of temperature or pressure is named as Advanced oxidation process or AOP. The effectiveness of oxidation is dependent on the type of ion radical intermediate or oxidant formed and their oxidation potential. Table **1** depicts the differences in the oxidation potential (eV) of various such oxidants.

**Table 1. Oxidation potential of some compounds.**

| **Oxidizing Agent** | **Oxidation Potential (eV)** |
|---|---|
| Nascent oxygen | 2.42 |
| Chlorine | 1.36 |
| Chlorine dioxide | 1.57 |
| Fluorine | 3.06 |
| Hydrogen peroxide | 1.78 |
| Hydroxyl radical | 2.8 |
| Hypochlorous acid | 1.49 |
| Oxygen | 1.23 |
| Ozone | 2.07 |
| Permanganate | 1.68 |

## CHAPTER 4

# Developments in Adsorption Technologies for Removal of Heavy Metals, Dyes, and Xenobiotics

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**Abstract:** Anthropogenic activities have led to widespread pollution in aquatic bodies due to extensive dissemination of refractory contaminants such as heavy metals, dyes, and xenobiotics. Adsorption is well recognized as a suitable technology for the removal of these pollutants. The major objective of this book chapter is to summarize recent advancement in this field. Accordingly, the book chapter starts with a brief introduction explaining the potential of the technology as compared to other competitive operations, followed by the identification of thrust areas to work on and the construction of a "template" to evaluate the progress in the technology. Next, recent developments in the preparation of various types of adsorbents (activated carbon-based traditional adsorbents, zeolites and clay minerals, adsorbents of biological origin, composite adsorbents having nanoparticles impregnated in a suitable matrix) have been elaborated. The chapter then focuses on how different process parameters may affect the efficiency of these adsorbents in removal of heavy metals, dyes, and xenobiotics. Finally, a comprehensive discussion has been made about how different mathematical models have been applied in recent times to fit experimental equilibrium and kinetic data obtained from the batch adsorption experiments, along with a critical evaluation of frequently used models. The chapter ends with a recommendation regarding future trends in adsorption technology.

**Keywords:** Adsorption, Biochar, Isotherms, Models, Nanomaterials.

## 1. INTRODUCTION

Heavy metals are ubiquitously used in medical, agricultural, and industries, such as metallurgy, electroplating, energy and fuel production, fertilizer and pesticide,

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electric appliance manufacturing among others [1]. Dyes are extensively used in the textile industries, leather tanning, paper, and colouring paper and fabric [2]. Polychlorinated biphenyls (PCB's) are useful as dielectric fluids, lubricants, plasticizers and heat transfer fluids. Increasing commercial application of heavy metals, dyes and other xenobiotic chemicals led to their widespread mobilization in the environment, mostly *via* the discharge of effluent without adequate treatment. Once mobilized, they continue to be accumulated in the ecosystem due to the non-biodegradable nature of these pollutants. These pollutants are toxic (mutagenic, carcinogenic, teratogenic) for human beings, even at a very low dose (in the order of parts per million), causing various health problems in the kidneys, lungs, and central nervous system and reproductive system [1]. Since fresh water is becoming limited in supply due to rapid urbanization, the use of wastewater for agriculture and irrigation is often encouraged. The bioaccumulation and bioaugmentation of these persistent contaminants by food chain could be most damaging for human beings who are present at the top of the food pyramid.

Conventional technologies for the removal of these pollutants include coagulation, membrane filtration, adsorption, oxidation, electrodialysis, biological treatment, ion exchange, and photocatalysis. But adsorption technology is advantageous due to its high effluent quality (compliance to regulatory criteria), environmentally benign operation (low sludge generation), and low operative cost (moderate requirement of reagent and energy) [3]. All of these factors become more prominent in the treatment of high-volume dilute discharge, usually encountered in effluent containing heavy metals, dyes and xenobiotics. Accordingly, adsorptive removal of these contaminants has become a thrust area of research in recent days.

The objective of this article is to focus on recent progress in adsorption technology in development of novel adsorbents capable of binding pollutants such as dyes, heavy metals and xenobiotics. The article will review all different aspects of the technology: a) laboratory synthesis of an adsorbent b) to elucidate the mechanism of adsorption c) parameters to consider in a batch adsorption process d) mathematical modeling of equilibrium and kinetic data obtained from batch experiments. For biosorbents, *i.e.*, adsorbents of biological origin, “synthesis” implies the identification and isolation of proper material through extensive screening. Besides good uptake capacity for target pollutant, stability and rigidity are two important criteria for the selection of biosorbent material. If it disintegrates or is not sufficiently rigid to be applied in a fixed-bed column reactor, additional processing (immobilization within a suitable matrix or granulation through cross-linking) may be required. Spent adsorbent may be desorbed using a suitable eluent for recovery of precious metal and regeneration of adsorbent for the next cycle of adsorption-desorption operation.

If promising results are obtained in a batch reactor, continuous operation may be tried using a fixed-bed reactor which is commercially preferred. In a fixed bed reactor, high adsorbent saturation can be achieved where the saturated adsorbent is in equilibrium with the incoming concentration. This review, however, will be limited to the batch study.

## 2. PREPARATION, CHARACTERIZATION, AND MECHANISM OF VARIOUS ADSORBENTS

### 2.1. Activated Carbon (GAC, PAC, Biochar)

The most frequently used adsorbents for binding heavy metals, dyes and other xenobiotics are activated carbon-based materials, zeolites and clay minerals, and biomaterials. Adsorbents based on activated carbon are well recognized due to their porous structure. Commercially available AC, such as granular activated carbon (GAC) (particles of size 0.5–1.5 mm) and powdered activated carbon (PAC) (particle size<0.2 mm), are generally prepared from coal, wood and coconut shell through pyrolysis [4]. Biochar refers to the thermal conversion of different biomass types into AC in oxygen-depleted atmosphere at temperatures ranging from 300 to 900°C. In a recent study, the FTIR and XRD data revealed that biochar prepared from switchgrass at a higher temperature (900 °C) was more graphitized than the one prepared at normal pyrolysis temperature (600 °C). The former was also found to have higher adsorption capacity for all three dyes tested (Methylene Blue, Orange G, and Congo Red) [5]. However, the carbon content for both biochars was similar. In a similar study investigating the effect of variation of temperature (from 400 °C to 800 °C) on biochar characteristics, the highest uptake of malachite green (5306.2 mg/g) by macroalgae-derived biochar produced at 800 °C was observed [6]. Biochar prepared from cladodes of *Opuntia ficus-indica* cactus was found to remove the malachite green dye, Cu(II) and Ni(II)through chemisorption [7]. Another biochar produced by direct pyrolysis of Palm petiole at 700 °C showed high carbon content (87%) with 209 mg/g of crystal violet dye uptake at neutral pH through pi-pi interaction, pore filling, and hydrogen bonding [8]. Typically, "activation" refers to an increase in pore volume and surface area done by physical (two step pyrolysis) or by chemical means. In a recent study, kelp seaweed (KE), owing to its higher ash content, was utilized to "activate" spent mushroom substrate (SMS) *via* co-pyrolysis [9]. The maximum adsorptive capacity for crystal violet, a cationic dye, was found to increase 2.2 folds for biochar prepared from 10%-KE added SMS compared to the one prepared from SMS only. However, biochar from KE-extract added SMS was found to have the highest carbon content (70.60%). Another study showed that both electrostatic interaction and chemical reactions with oxygenated functional

## CHAPTER 5

# Bioderived and Bioconjugated Materials for Remediation of Heavy Metals and Dyes from Wastewater

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**Abstract:** The present review draws on a wide range of resources available on bioderived, bioconjugated, chemisorption technologies and strategies known for degradation of heavy metals. The prevalent escalation in application of heavy metals, chemically synthesized dyes and xenobiotic compounds has created major environmental disruptions. Industries, mining, vehicles, and household activities release heavy metals and their derivatives into a multitude of water resources. Contaminated water provides an easy ingress of these contaminants into human and animal system resulting in exposure related disorders like mutagenesis, carcinogenesis and other serious health issues. Minimization and management of such chemicals demands high end technology, equipment, time, effort and cost. Thus, the less demanding but more effective strategy would be adoption of biosorption, using whole plant/microbial cells, components, derived and/or synthesized materials to convert toxic compounds/metals into less toxic forms. This review documents, critically analyses and collates heavy metals from mining, processing and industrial effluents followed by remediation technologies based on plants and microbes. Each section in the latter is discussed in detail with relevant examples that illustrate biosorption, bioderived, bioconjugated, chemisorptions, and bioremediation strategies. In the final analysis, though plant materials exhibit efficient removal strategies, particularly when augmented by nanomaterial conjunction, the commercial scale and viability remain to be validated.

**Keywords:** Biosorption, Bioderived, Bioconjugated, Bioremediation, Chemisorptions.

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# 1. INTRODUCTION

"When the wells dry, we know the worth of water" [1] is a hard fact of life, even in the 21st century, with all its technological prowess and progress. While, clean and fresh water resources have nurtured the evolution of civilizations, the industrial revolution on the other hand has escalated the degradation of global environment and resource depletion [2]. The rapidly growing human population, urbanization, and technological developments continue to exert untold stress on the aquatic ecosystems, with the concomitant loss of aquatic species at an alarming rate. This humungous loss negatively impacts the entire ecosystem, causes irreplaceable depletion in a spectrum of valuable resources that can be used in food, medicines and other applications [3]. Consequently, if the pollution level in a given water supply system (*e.g.*, domestic or industrial), exceeds levels recognized by various agencies/authorities, the water is demarcated unsafe or unhygienic for use, in a specific application [4]. The commonly adopted measures of resolution are point source pollution reduction and treatment of polluted water prior to use [4].

Heavy metals are major hazardous pollutants disseminated world wide by anthropogenic, geogenic and pedogenetic processes. Various natural phenomena like volcanoes, weathering of rock, flood, geochemical cycles, wind, industrial transportation, and excessive use of household products accelerate the pollutant levels in natural sources of water, air and soil [5].

## 1.1. Heavy Metals from Mining, Processing and Industrial Effluents

Kabata and Pendias [6] reported the pedogenic process of the parent material breaking down to ultimately form trace material (<1gm/kg), which is rarely toxic by nature. Various metal binding solids can originate from the wide variety of anthropogenic activities such as tailing, disposal of metal wastes and their leachate, leaded gasoline and paints, fertilizers, biosolids (sewage sludge), pesticides, coal combustion residues, petrochemicals, and atmospheric deposition [7 - 9]. Mercury is utilized in the electrical industry (switches, thermostats, batteries), dentistry (dental amalgams), and numerous industrial processes including the production of caustic soda, in nuclear reactors, as antifungal agents for wood processing, as a solvent for reactive and precious metals, and as a preservative of pharmaceutical products [10]. The adverse ecological fall out of soils contaminated by heavy metals have become critical environmental concerns. Toxic metals are considered as contaminants due to their widespread existence, and their acute and chronic toxic effect on plants [11].

A simple mass balance of the heavy metals in the soil can be expressed by the formula mentioned below [12, 13]:

$$M_{total} = (M_p + M_a + M_f + M_{ag} + M_{ow} + M_{ip}) - (M_{cr} + M_l)$$

where, $M$ - heavy metal, $p$ - parent material, $a$ –Atmospheric deposition, $f$ –fertilizer source, $ag$ – agrochemical sources, $ow$ – organic waste sources, $ip$ – other inorganic pollutant, $cr$ – crop removal, $l$ – losses by processes like leaching, and volatilization.

## 1.2. Heavy Metals Used in Agriculture

The first major human intervention on the soil was agriculture [14]. Crops require macronutrients like N, P, K, S, Ca, and Mg, besides essential micronutrients such as Co, Cu, Fe, Mn, Mo, Ni, and Zn, that are all essential for plant growth [15]. Application of fertilizers to crop fields increases crop efficiency, productivity, and product quality. The fertilizer industry is a significant source of chemicals containing toxic levels of heavy metals like Hg, Cd, As, Pb, Cu, Ni, and Cr [16]. *Ad libitum* application of chemical fertilizers in agriculture processes has resulted in release of toxic heavy metals, and created a large number of related environmental problems (Table **1**). Several arsenic-containing compounds produced industrially have subsequently been used to manufacture products with agricultural applications such as insecticides, herbicides, fungicides, and algicides [17].

**Table 1. Environmental threats and the their causes.**

| Type of Threat | Causes |
|---|---|
| Water Regime | Flooding; reclamation; water diversion; erosion/siltation; roads; irrigation; water works (floods) |
| Water Pollution | Solid waste refuse; siltation; sewage/fecal; mining; pesticides; fertilizers; salinization of soils |
| Physical Modification | Erosion; flooding; clearance and fire; sedimentation; infrastructure/housing; quarrying and sand mining; hunting; recreation |

## 1.3. Air Mediated Sources of Heavy Metals

In the air, heavy metals can accumulate from the sources such as mining process, fossil fuel combustion, metallurgical process, incineration activities, industrial plants and even from windblown soil and dust [18]. Han and Naeher [19]

## CHAPTER 6

# Trends in Bioremediation of Dyes from Wastewater

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**Abstract:** Over 100 tons of dyes are released per year into the wastewaters without prior treatment which adds to the contamination of freshwater resources globally. Thus, the development of economical, and sustainable control measures to avoid the pollution of natural resources remains imperative. In the present scenario, recent advancements in biological approaches have escalated bioremediation as a potential strategy for treatment of dyes and associated derivatives. These biological approaches utilize simple to complex microorganisms, plants, and wastes generated from different animal products as tools to remediate and remove dye molecules from wastewater. This particular chapter targets to address the recent advancements in the past three to four years in the sustainable treatment of dye molecules from wastewater using bioremediation approaches. The study also includes the prevailing hurdles, and research prospects in the bioremediation techniques utilized for the reduction of dyes from wastewater.

**Keywords:** Biodegradation, Biomaterials, Composites, Dyes, Nanosized compounds.

## 1. INTRODUCTION

In the present scenario, contamination of freshwater resources remains a major problem attributed to the unsupervised discharge of industrial wastewaters without prior treatment [1]. To worsen, uncontrolled increase in industries under different sectors which are not limited to printing, food, pharma, cosmetics, textiles, leather, *etc*., in order to meet the demand chain was evidenced in the past few decades [2]. These industries predominantly utilize over a million tons of

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dyes per year and release about 10% *i.e.,* ~100 tons of dyes per year into wastewater [3]. Among them, over 50% of the total dyes released are from textile industries which utilize over 1000 different varieties of dyes and pigments. Dyes possess strong structural stability and are certainly non-biodegradable in many cases which make them more harmful to the environment when released without proper treatment. The chemical nature of dyes can vary from simple, biodegradable, natural pigment molecules to complex polyphenols, para-nitrophenol, pyrene, *etc*., which are carcinogenic in nature. These dyes can be classified based on their mode of applications, and based on their structural complexities. For instance, moderate dyes, vat, acidic, disperse, reactive, direct, sulfur, and basic dyes are the categories based on their application whereas azo, xanthene, nitrated, polymethinic, indigo, and many more are categorized based on their structural complexities [2]. Thus, the removal or degradation/ neutralization of all these complex color molecules remains one of the major tasks to be addressed. Conventional chemical-based treatment strategies such as adsorption, flocculation, filtration, precipitation, photocatalytic process, membrane dependent process, oxidation, *etc*., are utilized for the treatment of effluents containing dye molecules. In addition, novel treatment strategies involving combinatorial approach are being developed to either neutralize the dye or to remove the dye from effluent and reuse them. However, the task remains breath-taking for dyes with complex structures. In addition to that, these physico-chemical methods generate large volumes of sludge which must be dumped at a different site and requires high cost to meet the needs of chemicals involved in the treatment process and maintenance. Alternately, biodegradation strategies are gaining increased attention attributed to the availability of variety of microorganisms (bacteria, fungi, algae), biocatalysts (enzymes), and plants that are capable of mineralizing the complex dye molecules thereby generating reduced volumes of sludge. Thus, with growing environmental contaminants, reliance on biological treatment systems makes the process sustainable and ensures the non-generation of xenobiotic derivatives. This chapter targets to review the recent trends and advancements over the past three to four years in the field of bioremediation of dyes with various life forms, while highlighting the prevailing strategies, bottlenecks, and future prospects.

## 2. BIOLOGICAL TREATMENT OF DYES

Unlike physico-chemical treatment strategies involved in remediation of dyes, the biological treatment strategies are considered to be economically feasible and sustainable attributed to the reduced release of sludge. In case of biological treatment, a wide variety of treatment options could be opted which generally comprise techniques such as accumulation, sorption, degradation, and mineralization. In biosorption, the dye molecules are allowed to passively bind to the surface of dead or live microbes or agricultural residues or biological polymers, *etc*. which results in the removal of color from the wastewater. On the contrary, bioaccumulation is an active process that involves living cells of microbes or plants or animals that can accumulate the dye molecules in to their biomass composition through different uptake mechanisms. Usually, these assimilated dye molecules further undergo a serious of metabolic reactions within the biomass resulting in complete degradation or neutralization. Thus, the removal of dye molecules from wastewater through sorption, and accumulation techniques results in the discoloration of the wastewater effectively. The other technique involves the mineralization phenomena in which the dye molecules are converted into metallic crystals or precipitated through the metabolic reactions either in the active living organisms or through catalytic reactions mediated by enzymes derived from living organisms. Fig. (**1**) depicts the various mechanisms involved in the biological treatment of dyes from wastewater.

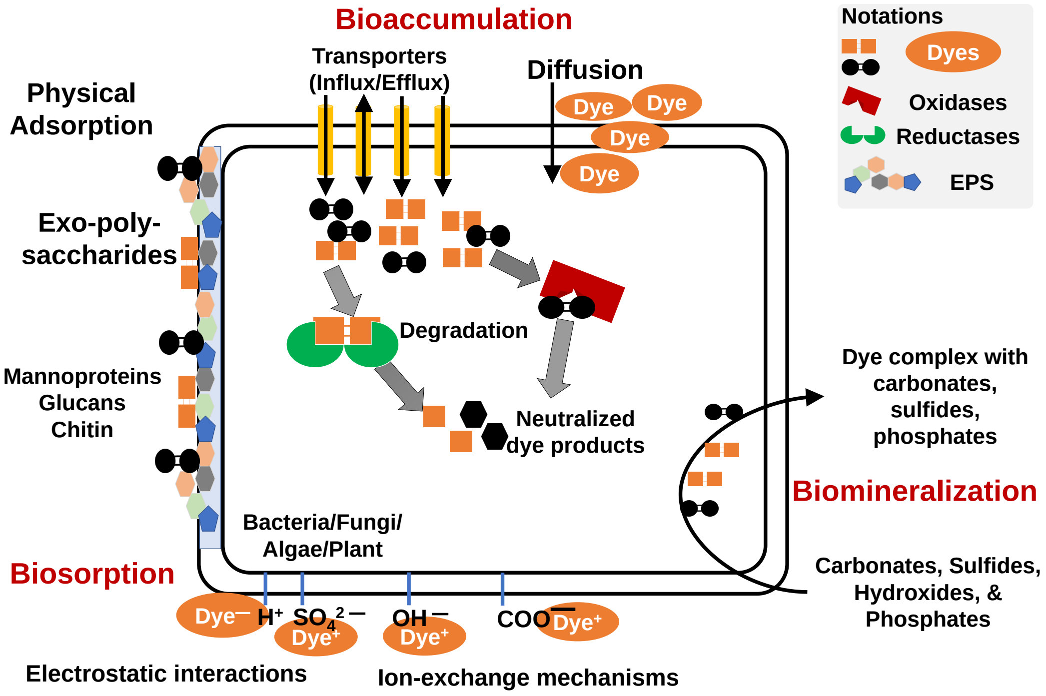

**Fig. (1).** Various mechanisms involved in bioremediation of dye molecules from wastewater through biosorption, bioaccumulation, biomineralization, and biodegradation.

## 2.1. Biosorption of Dyes

Adsorption with biological materials remains one of the attractive techniques in

## CHAPTER 7

# Bottlenecks in Sustainable Treatment of Wastewaters Using Physico-Chemical Processes and Future Prospects

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**Abstract:** This chapter covers bottlenecks in various sustainable physio-chemical processes including membrane filtration, activated carbon filtration, adsorption, advanced oxidation processes, dissolved air floatation, coagulation-flocculation and sedimentation, and electrocoagulation process for removing heavy metal ions, dyes, and xenobiotics from the aquatic environment. The approach taken in this chapter is to give a quick overview of each phase before focusing on the bottlenecks that these processes face when it comes to removing metal ions and organic matter from wastewater. Performance, cost, and sustainability criteria for sustainable wastewater treatment technologies are also covered in this chapter for each process.

**Keywords:** Bottlenecks, Economic feasibility, Physico-chemical process, Resource recovery, Sustainability.

## 1. INTRODUCTION

Wastewater is one of the most serious environmental challenges today, posing serious health and environmental risks to humans, animals, and the environment [1]. Inadequate management and technologies are too accountable for the aforementioned issues. Domestic, commercial, industrial, and agricultural discharges all contribute to wastewater. Pollutants and contaminants in waste water include nutrients, microbes, chemicals, and other poisons. When wastewater is inappropriately discharged into body rivers, these pollutants can cause health

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and environmental hazards [2]. Wastewater, on the other hand, contains reusable resources such as water, carbon, and nutrients, all of which can be collected and reused [3]. As a result, adequate pollution removal processes are required in order to meet effluent regulatory limits. Furthermore, resource recovery should be a priority in order to reduce carbon emissions and make the processes self-sustainable [4].

Wastewater treatment is a procedure that involves the use of a combination of physical, chemical, and biological treatments to help return healthy water to the environment. Because the wastewater problem is so serious, many engineers and scientists have been working on new technologies to come up with a viable solution. Treatment procedures that can eliminate dissolved organic material and hazardous compounds have been developed due to technological advancements. At this time, advances in scientific understanding and awareness of the global environment have led to the development of new technologies and systems that can minimize pollution in wastewater and recycle energy, with the ultimate objective of zero pollutant discharge. There is a lot of wastewater created every day in many developing countries because of their rapid growth. However, wastewater contamination is still an issue in developing countries. Weak regulations, poor management, the current economic condition, and the use of inadequate technologies are all contributing factors to the problem. It is critical to choose the right technology to tackle the problem. Wastewater treatment plants are frequently ineffective at removing heavy metals, dyes and xenobiotics from wastewater, allowing them to enter public sewers and the food chain, directly affecting humans and contributing to micropollutant pollution of aquatic bodies [5 - 7]. Activated sludge is typically not specialized enough for this activity, despite the fact that populations of bacteria and other microorganisms have been demonstrated to be successful in degrading/accumulating them [8 - 10]. Communities would have to adjust to the wastewater treatment conditions, which are economically unviable in traditional plants. Biological or physicochemical procedures that are more successful at removing them from water are being studied and improved substantially. As a result, the primary goal of this book chapter is to explain the bottlenecks of new approaches and sustainable techniques that can be employed to improve overall wastewater treatment.

## 2. BOTTLENECKS OF PHYSICO-CHEMICAL WASTEWATER TREATMENT PROCESS

The goal of a traditional physico-chemical wastewater treatment process is to remove solids such as colloids, organic matter, nutrients, and soluble pollutants (metals, organics, and so on) from effluents. As a result, the procedure to be utilised will be determined by the properties of the effluent. Each treatment has its own set of constraints, including cost, feasibility, efficiency, practicability, dependability, environmental impact, sludge production, difficulty of operation, pre-treatment needs, and the formation of potentially harmful by-products. However, just a few of the different wastewater treatment procedures now identified are commonly used by the industrial sector for technological and economic reasons.

## 2.1. Membrane Filtration

Membrane processes are a crucial technology for advanced wastewater reclamation and reuse techniques because they provide a reliable advanced treatment. They have several advantages, including the need for less space, the ability to act as a physical barrier against particle material, and the ability to keep microorganisms without generating resistance or the generation of by-products. Membranes are used in a number of large-scale advanced treatment schemes that are used around the world for artificial groundwater replenishment, indirect potable reuse, and industrial process-water generation. Ultrafiltration membranes (UF) filter out colloids, proteins, polysaccharides, bacteria, and even viruses, resulting in high-quality treated effluents. To separate ions and dissolved particles from water, nanofiltration (NF) and reverse osmosis (RO) are effective methods. In Singapore, as part of the NEWater project, NF/RO membrane technology was successfully used to recover water from wastewater for indirect potable reuse. The method involves multiple treatment phases and produces large amounts of reclaimed water, which is used to replenish natural drinking-water reservoirs in the city.

The membrane process, in combination with the activated sludge process, has been widely used for large-scale solid-liquid separation in wastewater treatment. In the process, separate management of sludge and hydraulic retention durations, as well as increased mixed liquor-suspended solids concentrations, could be beneficial. Kim *et al*. (2009) investigated the effects of granular activated carbon (GAC) on microfiltration (MF) performance in terms of permeate flux. When utilizing simply MF, the efficiency of pollutant removal with GAC was around 60%, compared to 30% when using only MF [11]. Hammami *et al*. (2017) used a hybrid technique that combines adsorption using powdered activated carbon (PAC) and ultrafiltration to remove color (*i.e*., acid orange 7) from aqueous solutions. It was found that the use of hybrid processing reduced UF membrane fouling and PAC dose, increased permeate flux, and improved color removal [12]. To remove levofloxacin (LEV) from effluents, Ullah *et al*. (2019) created a magnetic carbon nanocomposite (MCN). Then, by combining MCN with

## CHAPTER 8

# Sustainable Mitigation of Wastewater Issues Using Microbes: Hurdles and Future Strategies

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**Abstract:** Exponential growth in population associated with changing lifestyle patterns and industrial upheaval has led to the degradation of the most valuable renewable resource *i.e.* water. Contamination of water bodies of varying sizes across the world has resulted in mass-scale deterioration of health and environmental adversaries. Uninhibited disposal of domestic, municipal and industrial effluents onto water bodies has severely impacted the flora and fauna, in turn affecting human health globally. If unchecked, this would lead to an unmitigated disaster, which would be detrimental to the very existence of humans on the planet. Wastewater remediation, therefore, is of paramount importance to safeguard water bodies and prevent them from excessive pollution. To that end, novel, sustainable technologies for elevated nutrient removal from wastewater are the need of the hour. Bioremediation of wastewater is one of the most prolific and novel approaches directed towards the efficient elimination of contaminants coupled with their subsequent conversion into value-added products. Over the last few decades, microbial treatment processes have gained increasing momentum due to their ease and high efficiency compared to conventional treatment technologies. The chapter provides a detailed overview of various biological wastewater treatment methodologies such as bacterial, fungal, microalgal and microalgae-bacteria consortium-mediated bioremediation.

**Keywords:** Bioremediation, Bottlenecks, Microalgae-bacteria consortium, Mycoremediation, Wastewater treatment.

## 1. INTRODUCTION

Scientists have been searching for decades for another suitable planet to inhabit both in our galaxy and beyond. However, their expeditions have not been fruitful

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mainly due to the absence of suitable environmental conditions on other planets similar to earth. One of the key factors pertinent towards thriving sustenance of any life form on earth is the presence of water. Water is reported to constitute more than three quarters of our planet, which has been instrumental in maintaining environmental balance to support flora and fauna. Water is one of the utmost key renewable sources which are essential for thriving existence of all life forms, nutrition, socio-economic advancement and maintenance of overall climatic health [1]. The importance of fresh water is widely accepted and acclaimed, yet, the exponential increase in population associated with industrialization and economic flourish has adversely impacted the quality and availability of fresh water on a global scale [2]. Water pollution is a man-made phenomenon owing to the unwanted and inadvertent discharge of excess inorganic, organic and xenobiotic compounds into aquatic bodies [2]. The continual dissemination of untreated nutrients into water bodies results in eutrophication and detrimentally impacts its beauty, and biological and pecuniary values. The ever-rising fear over degrading water quality has resulted in the formulation of more strict regulatory policies towards the dissemination of wastewater into the environment. To that end, there has been a conscious move directed towards the development of bioremediation tools that permit improved removal [3]. Anthropogenic activities and industrial operations have directly resulted in the magnification of toxic substances in the environment, negatively impacting the global health [4]. Statistically, the world is poised to encounter a water deficit of 40% by the year 2030 due to the exponential usage of water, its contamination, and a lack of suitable and sustainable technologies for treatment [5]. Decades of urbanization and industrialization have resulted in 80% rivers being contaminated by organic resources, nitrogen, phosphorous and heavy metals [6]. Humanity in the present century is concerned with quality water and alternate energy supply [7]. Pollution of the surface and groundwater resources has become a key environmental hazard affecting both humans and animals alike. This is a grave issue in developing countries, where human is at risk due to the compounding and continual increase of water pollution due to uninhibited release of heavy metals, organic substances, sewage, municipal waste dumping, *etc* [7].

Wastewater may be conventionally distributed into three categories depending on their source of their origin such as: (i) municipal wastewater which contains low amounts of toxicants and poisonous substances, (ii) agricultural wastewater is comprised mostly of animal manure, fertilizer and high concentrations of inorganic and organic nutrients and (iii) industrial wastewater arising as effluent streams is heavily laden with complex and toxic heavy metals with an inadvertently high COD content. The presence of organic and inorganic nutrients in municipal and agricultural wastewater renders them feasible and suitable options towards treatment and recovery whereas the presence of complex and toxic components in industrial effluents poses a major challenge in designing physical, chemical and biological treatments [5]. Wastewaters exuding from different sources have typical physico-chemical properties such as nutrient concentration, pH, temperature of substances, chromaticity, toxic heavy metals, and phenolic which are essential in understanding and designing suitable treatment strategies. The wastewater treatment is majorly accomplished with the following goals: (a) Transforming substrates present into valuable products that are suitable for disposal, (b) ensuring health of the society, (c) conferring efficient handling of wastewaters on a trustworthy basis, (d) reimagining and recycling wastewaters, (e) development of sustainable treatment processes and dissemination techniques and (f) adhering to governing regulations and policies for discharge and disposal [8]. The ultimate objective of wastewater control and management is to safeguard the environment which, in turn will offer a positive influence on human health.

Physical treatment of wastewater is amongst the first methods to be successfully demonstrated towards wastewater treatment using physical unit operations deploying mechanical forces [9]. Physical treatment processes are still prevalently used coupled with chemical treatments in which certain catalysts are used to lower the toxicity of the wastewater. However, there is an inherent disadvantage of the overall chemical treatment strategies that they are always used in conjunction with physical processes and they often add constituents into the wastewater, rendering them significantly infeasible for further reuse [9]. Treatment through biological means is currently gaining traction as the processes involve the use of microbial communities which successfully remove toxic pollutants and subsequently produce value-added chemicals. The three treatment processes have been used in combination to enhance treatment efficiency (Fig. **1**). These combinations have been denoted as primary, secondary and tertiary wastewater treatment [10]. These methods are employed for achieving maximum contaminants' and organic removal from wastewater, making it suitable for dissemination and recycling [11]. Primary treatment is mainly focussed on the physical separation of the heavy solids, lighter solids, oil and grease by gravitational settling [9]. The decanted liquid is further processed *via* secondary treatment where the soluble and remaining suspended matter is removed by the action of indigenous water-borne microbes [12]. Furthermore, tertiary treatment involves purification, coupling, biological digestion, and physicochemical flocculation / purification for nutrient removal before discharging it onto freshwater bodies.

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## Biswanath Bhunia

Dr. Biswanath Bhunia received a PhD in 2012 from National Institute of Technology Durgapur's Biotechnology Program and Fast Track Young Scientist award from the Department of Science and Technology of the Government of India in 2012. Following completion of his PhD, Dr. Bhunia joined academia as an Assistant Professor in the Department of Bioengineering at the National Institute of Technology Agartala in 2013. Dr. Bhunia is working on various secondary metabolite production using fungal, bacteria, cyanobacteria, algae etc. He has authored or co-authored 80 peer-reviewed papers, ten book chapters, and presented at numerous national and international conferences on topics ranging from bioprocess engineering, bioinformatics, enzyme and microbial technology, advanced purification process and modelling. Dr. Bhunia' teaching interests are focused on Bioprocess Engineering, Environmental Biotechnology, and Bioinformatics.

## Muthusivaramapandian Muthuraj

Dr. Muthusivaramapandian Muthuraj is currently working as Assistant Professor in the Department of Bioengineering, National Institute of Technology Agartala, India. He received his Ph.D. from the Department of Biosciences and Bioengineering, at Indian Institute of Technology Guwahati, India in the year 2015. His research interests include bioenergy production, microalgal biotechnology, and sustainable bioprocess for synthesis of value- added biochemicals. He has industrial experience for over two years, where he developed a process for production of hyaluronic acid from *Streptococcus* sp. He is a certified reviewer for Bioresource Technology Reports, MDPI, and other reputed journals. He has a total h-index of 12 and i-index of 15, with over 30 publications in international peer reviewed journals and publications. He has also published several book chapters, and gave lectures at various international and national conferences, and seminars. He is currently teaching biotechnology and biochemical reaction. engineering principles, metabolic engineering, modeling & simulation for biological systems