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7. Organic Pollutants: Impacts and Degradation Methods

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Abstract:

The presence of organic pollutants, such as organochlorine pesticides, halo hydrocarbons, polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons (PAHs), dyes, and petrochemical products, has become a growing environmental concern due to their detrimental health effects. Despite the global ban on certain classes of organic pollutants, they continue to be produced through both intentional and unintentional industrial activities. Given their chronic impact, it is imperative to monitor and remediate these pollutants. This chapter provides an overview of the current status of methods for degrading organic pollutants in water and soil. Specifically, biological, physical, chemical, and advanced oxidation processes for treating organic pollutants are discussed. Additionally, emphasis is placed on understanding the physiochemical properties of these pollutants in the presented matrix to identify optimal solutions for their removal. Furthermore, the impacts of organic pollutants on human health and the environment are also discussed, highlighting the importance of raising awareness and minimizing their uses.

Keywords:

Organic pollutants, sources, impacts, health, and degradation.

7.1 Introduction: Organic Pollutants:

Due to the increased industrialization, a variety of natural activities, and uncontrolled human willingness, chemical pollutants have infiltrated the soil, water, and atmosphere worldwide [1].

Organic pollutants are synthetic chemicals that originate from industrial activities and a lack of proper management. These pollutants are typically classified based on their boiling points [2], which reflects their chemical properties and ecological fate, as well as the diagnostic methods used for their detection. Organic pollutants encompass a range of organic compounds, including methane, propane, butane, benzene, and xylene, among others. The primary sources of these pollutants are agricultural activities, petrochemical industries, and organic solvents. While gases such as methane, ethane, propane, and butane are not classified as organic pollutants, their halogenated derivatives fall under this category. Organic pollutants include a diverse array of industrial chemicals, petrochemicals, pesticides, phenols, carbonyl compounds, ethers, aliphatic and aromatic esters, anilines, pyridines, and many others [3].

These pollutants are present in trace concentrations in various matrices, including soil, water, sediments, and air. Due to their persistent stability in the environment, bioaccumulation potential, long-range transportability, and environmental toxicity, they are internationally recognized as persistent organic pollutants [4].

7.2 Effect on Health and Environment:

Organic pollutants have a tendency to accumulate in the environment through the food chain, owing to their high fat solubility. Consequently, they are typically found at elevated concentrations in fat-containing foods such as milk, eggs, fish, and meat, resulting in their subsequent accumulation in the human body. Organic pollutants can be categorized as polycyclic aromatic hydrocarbons (PAHs), perfluoroalkyl and polyfluoroalkyl substances (PFASs), pesticides (halogenated organic compounds), brominated flame retardants (BFRs), and so forth [5]. These pollutants are known to have deleterious health effects, including abnormal growth, brain malfunction, hormonal imbalance, metabolic disorders, and others [6, 7]. Chronic exposure to organic pollutants may also result in immunological effects [8], type 1 immune responses [9], allergy epidemics [10], asthma [11], cancer, reproductive defects, diabetes, and so on.

7.3 Sources of Organic Pollutants:

Fire is considered to be the definitive foundation of organic pollutants, which can result from intentional, accidental, and premeditated burning of flora [12]. These pollutants are known to enter the atmosphere due to human-originated activities, such as various industrial sources, power stations, transportation, evaporation from soil and water surfaces, heating posts, domestic heaters, landfill transference, and usage of agronomic posies. In addition, the causes of organic pollutants can be attributed to uncontrolled chemical amenities, forestry fires, PCBs waste decay, and other factors, which originate from various sectors such as constructions, evaporation, cement trades, coal ignition, oil combustion, and reprocessing actions, municipal incineration, organochlorine pesticide plants, aluminum secondary plants, furnace and foundry coke construction, plants dangerous waste/plastic waste in landfills, organochlorine pesticide storage, and sewage sludge [13]. Natural events, including volcanic activities and forest fires, are also known to release dioxins and dibenzofurans, which contribute to organic pollutants. The wastewater and runoffs from plants or using organic pollutants, as well as atmospheric depositions, are the primary sources of accumulation of organic substances in environmental matrices, including soil, water, and sediments. Marine ecology serves as the principal reservoir for these pollutants, where they can accumulate through various means, such as river orientation and environmental settling. Generally, they are deposited over cradles of different sediments of water bodies, where they can be released after a period and reintroduced to the atmospheric region [10].

7.4 Degradation Methods for Organic Pollutants:

Conventional methods of remediation, including incineration, chemical metal reduction, solvent extraction, ground filling, and stabilization or solidification, are employed to eradicate organic pollutants from soil and sand residues. However, the management of such intricate infrastructure and the employment of skilled personnel with expertise in operating analytical instruments pose a significant challenge due to their exorbitant cost. Moreover, these methods are not entirely effective in eliminating toxic organic pollutants [14]. Consequently, alternative approaches are utilized to achieve complete elimination of organic pollutants as follow:

7.4.1 Biological (Biodegradation) method:

One method i.e. biodegradation can get rid of the toxic organic compounds more effectively from water and soil through applying microorganisms [15]. The biodegradation system works without affecting the other parameters and does pure the environment. The naturally existing microorganism degrades the typical chemical substances into smaller non-harmful through a process called bioconversion [16, 17].

The technique offers excellent outcomes in terms of eco-friendliness, prominence, effectiveness, and economical acceptability over previous traditional techniques.

Several microorganisms, including bacteria, fungi, and algae, have been reported to play a significant role in the transformation and remediation of toxic organic pollutants. Among these microorganisms, Bacillus has been found to be particularly effective [18].

Various techniques, such as biostimulation, biosparging, bioaugmentation, and bioventing, have been employed to eliminate organic contaminants. Bioventing involves aerating the soil and water to facilitate the subsequent biodegradation of organic substances [19, 20].

Biostimulation involves the conversion of pollutant substances and the addition of other nutrients to the medium to maintain a balanced pH ratio and C:N:P ratio, which supports soil microorganism activities [21]. Bioaugmentation involves the insertion of microbial groups, such as bacteria or fungi, and other biocatalysts, such as genes or enzymes, to facilitate the degradation of organic/inorganic toxic compounds [22].

In bioremediation, both aerobic and anaerobic conditions are applied for pollutant degradation. Aerobic conditions require molecular O_2, such as mono- and dioxygenase, to act as an electron acceptor and co-substrate. In contrast, anaerobic conditions only require the presence of electrons for microorganisms to transform and degrade molecule assemblies into CO_2, H_2O, and inorganic compounds (salts). Chlorinated compounds that are difficult to degrade are generally subjected to anaerobic conditions for their degradation [23].

A varied community comprising molds, yeast, and filamentous fungi is predominantly employed in the degradation of organic pollutants. Fungi possess the ability to enhance soil permeability and ion exchange strength, thereby facilitating the further decontamination of soil from pollutants. Several fungal species, such as Fusarium oxysporum, Trametes versicolor, and Phanerochaete chrysosporium, have been documented for their ability to degrade persistent toxic pollutants, including DDT, through the utilization of oxidation/reduction mechanisms. The exploration of diverse mycelia types has been demonstrated to be effective in the oxidation of aromatic compounds and their derivatives, such as pyrene and halogenated pyrenes.

7.4.2 Chemical method:

The Fenton process, a traditional applied chemical approach, involves the application of a mixture of a soluble iron (II) salt and H_2O_2, known as Fenton's reagent, to degrade and eliminate pollutants. This process works by degrading H_2O_2 to produce highly reactive hydroxyl radicals, which effectively degrade organic pollutants in water and wastewater sediments [24].

However, with advancements in chemical processes, new technological approaches such as microwave (MW) and high-intensity ultrasound (US) are commonly used for the chemical degradation of organic pollutants. These approaches result in the degradation or conversion of organic pollutants into small amounts of inorganic ions, non-harmful chemicals, and mineralized compounds such as CO_2 and H_2O. Under US or MW heating, rapid degradation of pollutant water containing aromatic halides, halogenated phenols, and polychlorinated biphenyls can be achieved at a neutral pH. In acidic conditions, acidification with sulphuric acid to a pH of 1.7-2.0 facilitates complete degradation. Conversely, degradation and elimination of organic pollutants and other humic substances from soil matrices can be achieved using 0.1 or 0.5 N aqueous alkaline solutions of NaOH or KOH [25].

7.4.3 Oxidation approach:

Advanced oxidation approaches are considered to be the foremost, favorable, effective, and eco-friendly methods for the removal of organic pollutants from various types of water. These approaches primarily rely on the utilization of hydroxyl radicals (•OH) for their oxidative capabilities [26].

It is recommended that these methods be employed for the degradation and conversion of organic pollutants through water or wastewater treatment [27]. Different advanced oxidation approaches rely on various chemical, photochemical, or electrochemical reactions, offering a promising, innovative, and environmentally friendly technique for the separation of organic pollutants from water.

These methods are known to involve reactions such as chemical, electrochemical, and photolytic processes, leading to the formation of intermediate hydroxyl radicals. The most commonly used approach is the Fenton method, specifically designed for the degradation and elimination of organic pollutants. However, the efficiency and utilization of this method can be significantly enhanced through the use of ultraviolet light or sunlight [28].

7.5 Conclusions:

The chapter provides a concise overview of organic pollutants, their sources, and the adverse health effects they pose, with particular emphasis on the necessity for their degradation. Additionally, the text explores a growing inclination towards employing biological and chemical methods for the degradation of organic pollutants. These approaches yield the breakdown or transformation of organic pollutants into minimal quantities of inorganic ions, benign chemicals, and mineralized compounds, such as carbon dioxide (CO_2) and water (H_2O).

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