frontiers in Environmental Chemistry

SPECIALTY GRAND CHALLENGE
published: 22 November 2021
doi: 10.3389/fenvc.2021.792814

Grand Challenges in Chemical Treatment of Hazardous Pollutants

Varsha Srivastava *

Research Unit of Sustainable Chemistry, Faculty of Technology, University of Oulu, Oulu, Finland

Keywords: chemical treatment, electrochemical treatment, coagulation, precipitaion, flocculalion, emerging pollutants, heavy metal

INTRODUCTION

The tremendous growth in industrialization and urbanization has resulted in generation of large amount of wastewater as well as hazardous waste (Chai et al., 2021; Titchou et al., 2021). Heterogenous solid waste usually ends up in landfills which undergoes various physicochemical change (Xiong et al., 2019; Patel et al., 2021)The nature and composition of hazardous waste varies depending on the source materials. Leachate from landfill sites has the potential to affect the water quality if it further enters into water streams *via* rainwater/stormwater (Bishop et al., 1986; Gautam et al., 2019). Accumulation of hazardous pollutants result in soil, water and air pollution (Quesada et al., 2019; Alemany et al., 2021; Dionne and Walker, 2021; Nikolaeva et al., 2021; Yadav et al., 2021; Łyszczarz et al., 2021).

Heavy metals are widely used in different industries and due to their inefficient removal, they can directly or indirectly gain entry into water bodies. Metals are non-biodegradable and can easily accumulate in the environment (Gholizadeh and Hu, 2021; Xu et al., 2021). Different industries like textile, cosmetics, tannery, food and beverages release toxic bio-recalcitrant hazardous pollutants in the environment (Choina et al., 2013; Muszyński et al., 2019; Quesada et al., 2019; Keskin et al., 2021). The presence of both organic and inorganic pollutants in water bodies can harmfully affect the aquatic environment. Additionally, highly acidic or alkaline wastewater can also pose detrimental effects on aquatic environment.

Further, various organic pollutants like pharmaceuticals, EDCs, refractory organic and dyes can generate more toxic species due to degradation or interaction with other available pollutant species (Tijani et al., 2013). Sometimes, degraded byproducts are even more toxic in comparison to their parent compound (Yin et al., 2017). The presence of emerging contaminants (ECs) in the environment is of great concern due to their harmful impacts on one hand and great challenges in existing water treatment technologies in terms of their removal efficiency on the other hand (Ahmed et al., 2021; Zamri et al., 2021).

Consumption of polluted water can result in a great threat to living beings hence the wastewater needs to be properly treated before being discharged into the water bodies (Gitis and Hankins, 2018; Hussein and Jasim, 2021).

It is noteworthy that due to water scarcity and environmental pollution by emission of pollutants, there is a continual rising global concern regarding the treatment of wastewater in order to make it available for reuse (Hussein and Jasim, 2021; Patel et al., 2021). Due to inefficient traditional treatment technologies, varieties of pollutants reach into the environment which directly and/or indirectly affects flora and fauna. Removal of lower concentrations of pollutants is more challenging and varied concentrations of emerging pollutants can be detected in the municipal sludge and effluents of municipal wastewater treatment plants.

Hazardous waste and wastewater can be treated by physical, chemical, thermal, biological as well as physico-chemical methods. Conventional technologies like physico-chemical and biological treatment methods are mainly used for the treatment of wastewater and hazardous solid waste.

Edited and reviewed By:
Xitao Liu, Beijing Normal University, Beijing, China

****Correspondence:***
Varsha Srivastava
varshasrivastava.jyu@gmail.com

Received: *11 October 2021*
Accepted: *02 November 2021*
Published: *22 November 2021*

Citation:
Srivastava V (2021) Grand Challenges in Chemical Treatment of Hazardous Pollutants. Front. Environ. Chem. 2:792814. doi: 10.3389/fenvc.2021.792814

However, the efficient operation of these systems is energy-intensive and requires substantial operative and maintenance costs (Patel et al., 2021). The most promising approach for treatment of wastewater and hazardous solid waste requires recovery of possible resources, reduction of waste/wastewater and efficient removal of toxic pollutants (Ahmed et al., 2021). Existing wastewater treatment plants (WWTPs) technologies are unable to eliminate ECs hence low concentrations of these pollutants are detected in effluents.

Generally, the utilization of a single method for treating wastewater is not sufficient enough for ideal treatment. This issue can be handled by combining different processes following one after the other (Du et al., 2021; Huang et al., 2021; Hussein and Jasim, 2021). In recent years, hybrid systems, involving both conventional as well as advanced treatment processes, have received greater attention due to their enhanced efficiency in the removal of hazardous pollutants (Saúco et al., 2021; Kim et al., 2022). During the treatment of hazardous solid waste and wastewater, resources can be efficiently recovered whereas the treated wastewater can be reused for various applications.

Chemical treatments have been widely used for variety of hazardous pollutants and are very effective for solid waste as well as liquid waste or wastewater (Azbar et al., 2004; Reddy et al., 2010; Bustos-Terrones et al., 2021). Chemical treatment can alter the toxic waste into nontoxic end-products and help in their safe disposal. It mainly includes precipitation, ion-exchange, neutralization, oxidation, coagulation, flocculation and electrochemical process (Ullah et al., 2020; Patel et al., 2021).

Chemical treatments can effectively work on low/high concentrations of hazardous pollutants. The selection of any chemical treatment process is highly dependent on the target pollutants and their environment. It needs to be selected either alone or with a combination of other techniques to obtain efficient treatment results in a cost-effective manner and environmentally friendly approach with a view to meet the guidelines of environmental legislation.

Challenges in Chemical Treatment of Hazardous Pollutants

Chemical treatment has been found very effective in cases of hazardous solid waste, liquid-waste and wastewater effluents, but it is always restricted due to high cost of chemicals and generation of secondary waste which further needs to be treated for safe disposal. Due to strict environmental legislation, hazardous waste must be treated with appropriate technology which helps in reduction and recovery of resources. Chemical treatment like chlorination is effective but it is associated with generation of disinfection by-products (DBPs) (Song et al., 2021). Another chemical treatment like ozonation is effective against numerous recalcitrant pollutants but this process is highly energy intensive (Ben Hamida et al., 2017; Ben Hamida et al., 2018). Low mineralization efficiency, selectivity towards pollutants and low solubility in water make this approach more expensive (Wang and Chen, 2020). Application of coagulants in conventional water treatment processes result in generation of significant amount of silt (Bouchareb et al., 2020).

Utilization of higher amount of chemicals for reducing and treating hazardous pollutants is not a worthy approach for a sustainable solution. Moreover, Fenton process is effective in degradation of organic pollutants, but it is associated with iron sludge generation and covers a narrow pH range (Azbar et al., 2004). Further treatment of secondary waste generated in Fenton process requires sustainable treatment. Catalyst based treatment is found to be very effective in treatment of emerging pollutants and a wide range of homogeneous and heterogeneous catalysts have been developed for this purpose (Hammouda et al., 2017; Minh et al., 2019). Due to lack of efficient catalyst recovery system, finer particles of catalyst may reach into the effluent streams or may end up in a solid sludge which can further pose harmful effects on the environment.

There is an increasing demand for development of efficient greener chemical treatment technologies in order to minimize the secondary waste and reduce the chemical consumption. More emphasis should be given to the green approach for synthesis of catalyst to reduce the toxicity of tailored catalysts (Yadav et al., 2021). Possibility to use greener technology using biobased materials, natural minerals for developing ion exchange material, coagulant or catalyst can make the process of chemical treatment safer and greener. Application of biobased chemicals for catalyst preparation can be effective in this sequence.

Further, the electrochemical method has gained popularity in recent few years as it does not require the use of chemical reagents like other chemical treatment methods as the oxidation of organic pollutants takes place over the electrode (Bouchareb et al., 2020). Electrocoagulation, Electro-Fenton process, Electro-catalytic ozonation, photoelectron-Fenton process, Electrochemical-persulfate oxidation processes have been found to be effective in the removal of various pollutants (Ltaïef et al., 2018; Martínez-Huitle and Panizza, 2018; Qiao and Xiong, 2021). However, development of high-quality electrode is still a challenging task and sometimes it is highly selective for pollutant species and there is always a need to perform some pretreatment steps in order to get effective results from electrochemical treatment approach. Further, leaching of toxic chemicals from electrode surface can generate trace concentration of chemicals in the effluents. However, electrochemical method by using green materials for electrode preparation can be very effective in terms of reduction of secondary pollutants. The combination of photocatalytic treatment and electrochemical treatment provides an emerging strategy to remove organic pollutants from waste streams.

In recent years, application of variety of chemicals in treatment of trace concentrations of emerging pollutants has increased but the adverse effects by accumulation of these chemicals in the environment are not studied well yet (Gitis and Hankins, 2018). Chemical treatments are very effective in the removal of wide range of hazardous pollutants from solid and liquid waste. On the contrary, they are highly dependent on the characteristics of the hazardous pollutants and need to be selected accordingly. There is a growing need for advancement in the effective ion exchange materials, catalyst materials, coagulant, efficient electrode materials for electrochemical approach etc. for an efficient and sustainable chemical treatment approach to provide safer environment.

The purpose of Chemical treatment "Specialty section within Frontiers in Environmental Chemistry" is to provide the latest and high-quality research paper and review paper in the research area of chemical treatment for hazardous pollutants from solid waste, liquid waste and wastewater.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Yati A.P. Srivastava, for her very helpful contribution and constructive comments. Financial support from the Academy of Finland (decision number 346537) is gratefully acknowledged.

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