Chapter 11
The Potential of Agricultural Waste Chars as Low-Cost Adsorbents for Heavy Metal Removal From Water

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ABSTRACT

Ensuring that every human being has access to clean and safe drinking water is a major global concern. The challenge of heavy metal contamination in water poses a serious risk to human health. This chapter aims to explore an eco-friendly and cost-effective solution to address water contamination issues. The focus is on using pyrolysis char derived from agricultural waste as a low-cost adsorbent to efficiently remove heavy metals from water. A thorough review of relevant literature, emphasising the advantages of pyrolysis char and highlighting recent advancements in the field, is performed. Additionally, an outline of potential challenges and future research direction in this promising area is given.

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INTRODUCTION

With the increasing anthropogenic activities attributed to technological advancements within chemical manufacturing, mining and agriculture, the deterioration of global water quality is imminent (Singh et al., 2023). This increase in demand for scarce water resources can best be abated through effective management and use of much more benign chemical processes, re-use efforts and pollution control. Water quality on the global platform varies significantly with developing countries generally bearing the brunt due to much more lenient regulations and inadequate pollution control attributed to limited infrastructure among other constraints. Despite stringent regulations, developed countries face high water treatment costs due to intense industrialisation. This highlights the urgent need for more cost-effective water treatment technologies. Industrial wastewater, containing pollutants like perfluoroalkyl substances and heavy metals, jeopardizes drinking water. Contamination makes water unsuitable for consumption, with treatment costs potentially soaring. Unchecked pollution leads to severe health issues in humans and wildlife, disrupting ecosystems and posing a significant threat to food security by altering predator-prey ratios. Carbon based adsorption materials have been at the forefront of water treatment and purification research in the past decade, these include activated carbon, carbon nanotubes, carbon aerogels and carbon black (Cheng et al., 2019). With agricultural activity on a global scope generating over 140 billion tonnes of agricultural waste annually (United Nations, 2009) which if pyrolysed could amount to above 70 billion tonnes of pyrolysis char based on reported char yields, biomass char becomes a readily available carbon-based adsorbent. Whilst activated carbon and other carbon-based materials have been utilised distinctly as adsorbents, recent advances have coupled the adsorptive capabilities of these materials with electro-motive techniques such as capacitive deionisation which allow for benign regeneration of the adsorbent and thus limiting the environmental burden (Cheng et al., 2019, Botha et al., 2021). Such a development also limits material handling and associated costs, thus paving a way for cheaper alternative water treatment methods. Pyrolysis biochar costs far much less than common commercial adsorbents. Commercial adsorbents are characterised by BET specific surface areas in the excess of 1500m^2/g (Yang et al., 2018) whilst pyrolysis char typically exhibits less BET specific surface area (< 500 m^2/g) thus limited adsorption sites (Tomczyk et al., 2020). However, despite specific surface area concerns, similar adsorptive mechanisms borne by these materials and the low cost of pyrolysis char are seen as attributes that would set the stage for a shift towards the widespread use of biomass char for adsorption tasks.

This chapter aims to position pyrolysis char as a viable alternative to current carbonaceous materials in water treatment. It provides a comprehensive overview of using pyrolysis char as an adsorbent, emphasising the optimal agricultural waste types for pyrolysis, process details, and the sustainability of this approach. The chapter also delves into sources of heavy metal contamination, associated risks, and existing mitigation technologies for treating contaminated waters. Material characteristics of pyrolysis char relevant to contaminant adsorption are explored, along with discussions on adsorption mechanisms and influencing factors. A comparative analysis of the effectiveness of various adsorbents against pyrolysis char is conducted to identify commonalities and strengths, aiming to pave the way for composite adsorption materials that balance cost and efficiency. Case studies highlighting the successful use of pyrolysis char in heavy metal removal, along with performance metrics, offer guidance for addressing challenges and advancing the technology. The chapter concludes by summarising key aspects discussed throughout.