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Advancements in Arsenic Removal from Drinking Water using Modified Biosolid Biochars: Adsorption-Desorption Behavior and Recyclability

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ABSTRACT

In the pursuit of safe drinking water, mitigating the perilous impact of arsenic contamination has gained paramount significance. The research on effective remediation methods is pivotal, particularly in comprehending the adsorption and desorption dynamics of arsenate (AsV) on modified biochars. This study investigates the adsorption and desorption tendencies of AsV utilizing biosolid-derived biochars, subject to modification with either single iron (Fe) or combined zirconium and iron (Zr–Fe). The biochars, namely Fe-chips (FeBSBC), Fe-salt ($FeCl_3$BSBC), and Zr–Fe-salt (Zr–$FeCl_3$BSBC) modified, were subjected to rigorous examination through various analytical techniques. Notably, X-ray photoelectron spectroscopy revealed the conversion of pentavalent AsV to the more hazardous trivalent AsIII form with $FeCl_3$BSBC and Zr–$FeCl_3$BSBC modifications. Equilibrium adsorption studies indicated substantial increases in AsV adsorption capacities, reaching 27.4 mg/g (pH 5) for FeBSBC, 29.77 mg/g (pH 5) for $FeCl_3$BSBC, and 67.28 mg/g (pH 6) for Zr–$FeCl_3$BSBC. Co-existing anions exhibited a varying influence on AsV removal efficacy. Moreover, a positive correlation with temperature demonstrated the endothermic nature of the adsorption process. Desorption and recyclability experiments exhibited the potential of the modified biochars for multiple cycles of AsV removal. This investigation presents a comprehensive insight into arsenic remediation through modified biosolid biochars, elucidating their adsorption behavior, recyclability, and potential for sustainable water purification solutions.

Keywords: Arsenic removal, Biosolid biochars, Adsorption-desorption, Modified biochar, Water purification.

INTRODUCTION

The contamination of drinking water sources with arsenic has emerged as a critical global concern due to its severe health implications. Traditional remediation

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methods often prove energy-intensive, expensive, and environmentally unsustainable. Consequently, the quest for sustainable and efficient arsenic removal techniques has led to the exploration of novel adsorbent materials such as biochars. Biochars, derived from biosolid sources, have exhibited potential as cost-effective adsorbents. However, the understanding of the adsorption and desorption behavior of arsenic on modified biosolid biochars remains limited. A critical gap in the existing research is the lack of comprehensive investigations that elucidate the mechanisms underlying the adsorption-desorption processes and assess the recyclability and practical applicability of these modified biochars for multiple cycles of arsenic removal. Addressing this gap could contributae significantly to the development of more effective and sustainable solutions for arsenic-contaminated water purification [1]-[2].

Recent studies in the field of arsenic removal from water have highlighted the potential of modified biochars as promising adsorbents. Biosolid-derived biochars, in particular, have gained attention for their cost-effectiveness and eco-friendly nature. Investigations into arsenic removal using biochars have mainly focused on single-component systems and the influence of various parameters on adsorption efficiency [3]-[4].

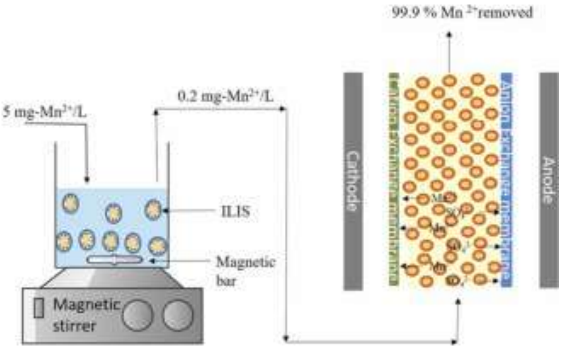

Figure 1. Removal of manganese (II) from aqueous solution by ionic liquid impregnated polymeric sorbent and electrodeionization (EDI) techniques.
https://www.sciencedirect.com/science/article/abs/pii/S0957582021006613

However, a comprehensive understanding of the adsorption and desorption behavior of arsenic on modified biosolid biochars, as well as their recyclability for practical applications, remains relatively unexplored. Therefore, there is a current research gap in elucidating the intricate mechanisms underlying the adsorption-desorption processes, as well as assessing the long-term efficacy and feasibility of these modified biochars for sustainable water purification solutions. Addressing these gaps would significantly contribute to advancing the field's knowledge and developing efficient, environmentally friendly approaches to combat arsenic contamination in drinking water [5]-[6].

This research introduces a novel approach to tackle arsenic contamination in drinking water by investigating the adsorption-desorption behavior and recyclability of arsenate (AsV) using modified biosolid-derived biochars. The distinctiveness lies in the exploration of binary modifications with both single iron (Fe) and zirconium-iron (Zr-Fe) combinations, shedding light on the potential synergy between these elements for enhanced arsenic removal. The study aims to decipher the underlying mechanisms responsible for AsV adsorption and desorption on these modified biochars, thereby bridging the gap in understanding their reversibility and regenerative properties [7]-[8].

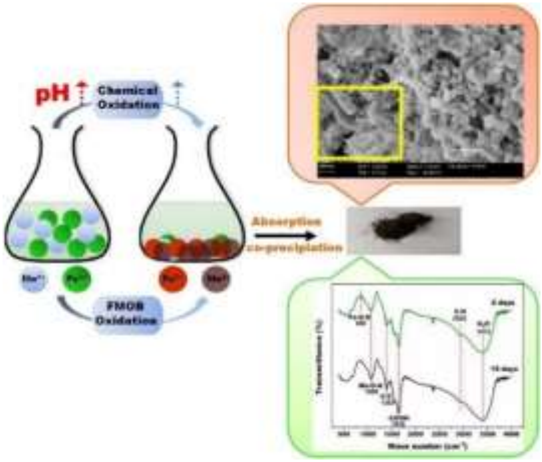

Figure 2. Simultaneous removal of iron and manganese from acid mine drainage by acclimated bacteria. https://www.sciencedirect.com/science/article/abs/pii/S0304389420306208

The primary objective of this research is to unravel the intricate adsorption-desorption dynamics of arsenic on Fe and Zr-Fe modified biosolid biochars and assess their viability for repeated cycles of arsenic removal, contributing to the development of sustainable water purification strategies.

METHODS

Research Methods

In this study, biosolid-derived biochars were prepared as the foundational adsorbent material. The biosolid feedstock underwent pyrolysis at controlled temperatures, followed by modification through two approaches: (1) incorporation of single iron (Fe) elements and (2) the formation of zirconium-iron (Zr-Fe) binary modifications [9]-[10].

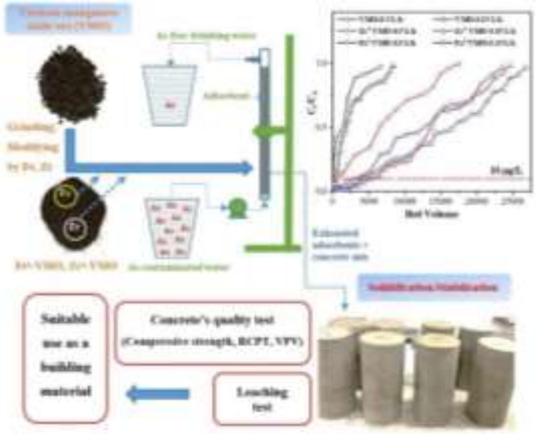

Figure 3. Removing arsenate from water using modified manganese oxide ore: Column adsorption and waste management. https://www.sciencedirect.com/science/article/abs/pii/S221334372030840X

The Fe-modified biochars were synthesized using Fe-chips (FeBSBC) and Fe-salt ($FeCl_3$BSBC), while the Zr-Fe modified biochars were obtained through Zr-Fe-salt (Zr-$FeCl_3$BSBC) addition. The physicochemical properties of the resulting biochars were characterized using techniques such as X-ray photoelectron spectroscopy, surface area analysis, and electron microscopy. The adsorption-desorption behavior of arsenate (AsV) onto these modified biochars was investigated through equilibrium adsorption studies, with varying solution conditions including pH and co-existing anions. The study also involved assessing the regenerative potential of the modified biochars by subjecting them to multiple adsorption-desorption cycles. This research employed a comprehensive analytical approach to unravel the mechanisms underpinning AsV adsorption and desorption on modified biosolid biochars, aiming to contribute to the development of efficient and sustainable solutions for arsenic-contaminated water purification [11]-[12].

Standard and Procedure

The research adhered to rigorous standard procedures in the preparation and characterization of biosolid-derived biochars and their modifications. The biosolid feedstock was carefully selected and subjected to controlled pyrolysis temperatures to ensure consistent biochar production. The Fe-modified biochars (FeBSBC and $FeCl_3BSBC$) and Zr-Fe modified biochars (Zr-$FeCl_3BSBC$) were synthesized with precise quantities of Fe and Zr-Fe salts, following established protocols [13].

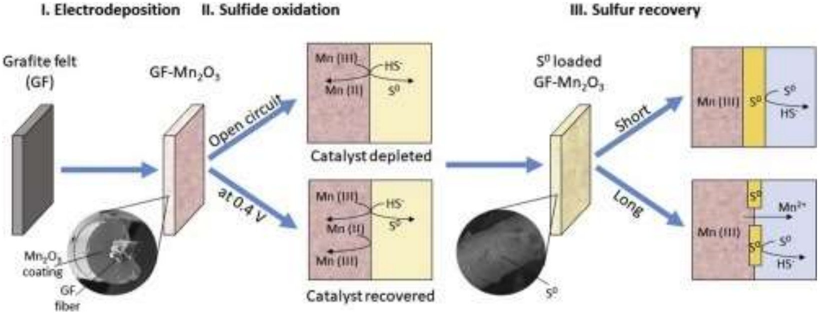

Figure 4. Manganese oxide-based porous electrodes for rapid and selective (electro)catalytic removal and recovery of sulfide from wastewater.
https://www.sciencedirect.com/science/article/pii/S0926337320300230

Characterization of the biochars included surface area analysis using techniques such as BET analysis, microstructural investigation through scanning electron microscopy (SEM), and elemental composition determination employing energy-dispersive X-ray spectroscopy (EDX) [14]-[15].

To examine the adsorption-desorption behavior, equilibrium adsorption studies were conducted under varying conditions of pH and co-existing anions to emulate real-world scenarios. The use of standardized solutions, with accurate AsV concentrations, pH adjustments, and thorough mixing, ensured consistent and reproducible results.

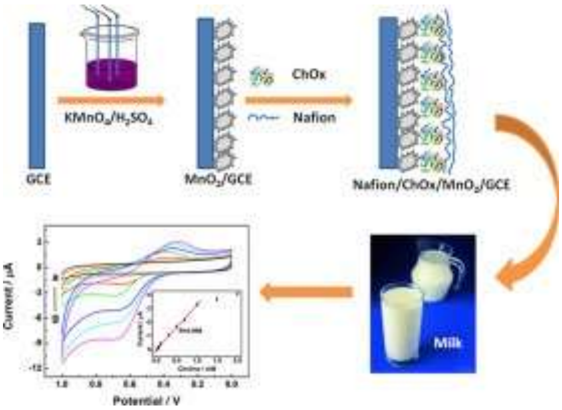

Figure 5. A facile and practical biosensor for choline based on manganese dioxide nanoparticles synthesized in-situ at the surface of electrode by one-step electrodeposition.
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Additionally, the evaluation of the regenerative capacity of the modified biochars involved subjecting them to multiple adsorption-desorption cycles, providing insights into their reusability and practical applicability. The comprehensive experimental procedures adhered to established protocols, ensuring the reliability and reproducibility of the research outcomes [16]-[17].

The methodology employed in this research included meticulous data collection and analysis techniques. The results of the equilibrium adsorption studies were fitted to the Langmuir isotherm model, and the maximum adsorption capacities were calculated. Co-existing anions' impact on AsV removal was systematically evaluated to understand potential interference. The quantification of pentavalent AsV and trivalent AsIII species through X-ray photoelectron spectroscopy enabled the elucidation of conversion mechanisms.

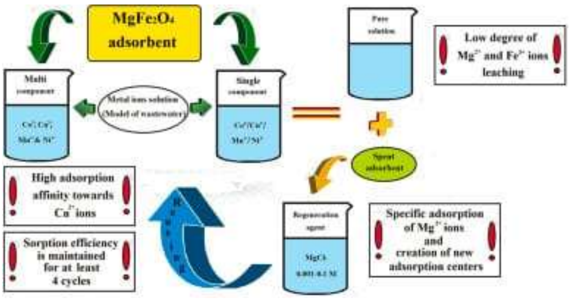

Figure 6. Effect of Mg^{2+} ions on competitive metal ions adsorption/desorption on magnesium ferrite: Mechanism, reusability and stability studies. https://www.sciencedirect.com/science/article/abs/pii/S0304389420328934

Additionally, the assessment of regenerative capacity involved quantifying the AsV removal efficiency across multiple cycles to ascertain the practical sustainability of the modified biochars [18]. These rigorous methodologies were meticulously followed to ensure accurate and insightful findings for advancing the field of arsenic removal from drinking water [19]-[20].

Data Collection Technique

Data collection in this study involved a systematic approach to gather information on the adsorption-desorption behavior of arsenate (AsV) onto modified biosolid biochars. Equilibrium adsorption studies were conducted by preparing a series of AsV solutions with precise concentrations. pH adjustments were made to replicate various environmental conditions. The prepared solutions were mixed with the modified biochars, and samples were collected at equilibrium [21].

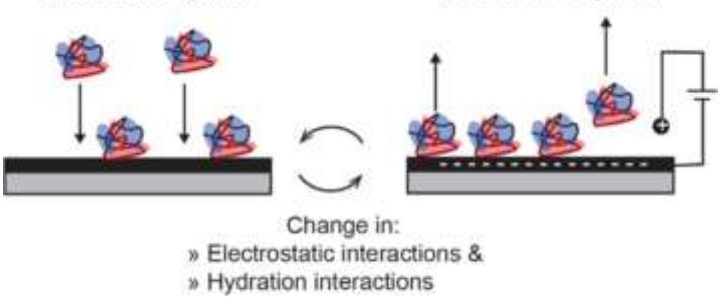

Figure 7. Electrode Surface Potential-Driven Protein Adsorption and Desorption through Modulation of Electrostatic, van der Waals, and Hydration Interactions. https://pubs.acs.org/doi/10.1021/acs.langmuir.1c00828

The concentrations of AsV in the collected samples were analyzed using appropriate analytical techniques, such as spectrophotometry. Co-existing anions' influence was studied by introducing them individually into the adsorption system, followed by quantifying the remaining AsV concentration. X-ray photoelectron spectroscopy was employed to identify the conversion of AsV to AsIII on the biochar surface. Additionally, the regenerative capacity of the modified biochars was evaluated through multiple adsorption-desorption cycles, and data were collected by analyzing the efficiency of AsV removal across cycles. This meticulous data collection process enabled a comprehensive understanding of the adsorption-desorption dynamics and the potential practicality of the modified biochars for sustainable arsenic removal [22]-[23].

Data Interpretation Technique

The interpretation of data in this research involved a systematic approach to derive meaningful insights from the experimental results. Equilibrium adsorption data were analyzed using Langmuir isotherm modeling to determine the maximum adsorption capacities and assess the adsorption efficiency of the modified biochars. The influence of co-existing anions was interpreted by comparing the adsorption capacities in their presence, shedding light on potential interference. The conversion of AsV to AsIII on the biochar surface, as indicated by X-ray photoelectron spectroscopy results, was interpreted to understand the transformation mechanisms facilitated by different modifications. The regenerative capacity data were interpreted by analyzing the variations in AsV removal efficiency across multiple cycles, providing insights into the practical applicability of the modified biochars over extended use. The comprehensive interpretation of these diverse datasets allowed for a nuanced understanding of the adsorption-desorption behavior, conversion processes, and regenerative potential of the modified biochars, contributing to the broader understanding of sustainable arsenic removal strategies [24]-[25].

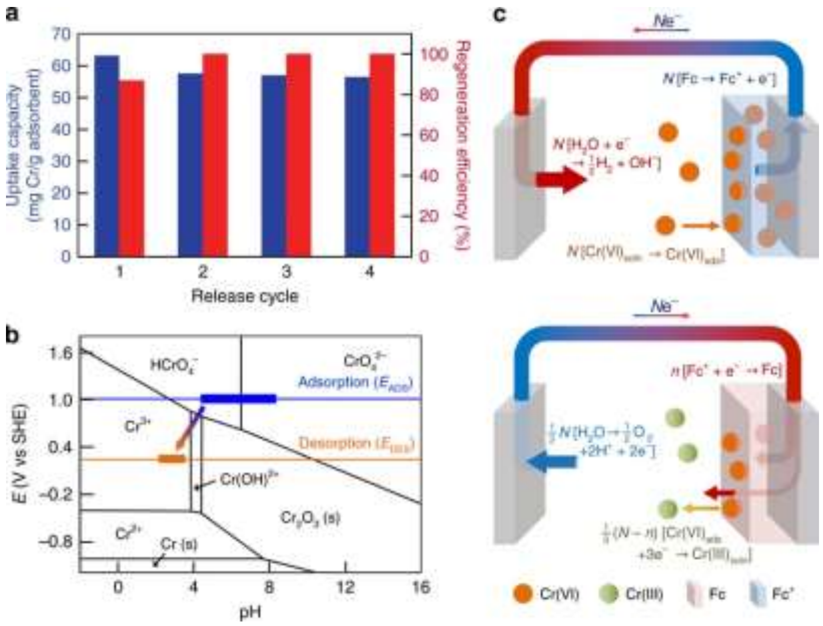

Figure 8. Investigation of the reversibility of the electrochemically mediated capture-and-release process. a Recyclability of the electrode over a number of discharge cycles (+0.8 V adsorption, 0 V discharge), as given by the normalized mass released (in blue), and the regeneration efficiency (%) (in red), the latter denoting the relative amount of Cr recovered relative to that adsorbed in each cycle. b The E-pH diagram for chromium speciation predominance, constructed with commercial thermochemical software (FactSage) at 25 °C for 1 mM total chromium concentration in the liquid phase. The adsorption and desorption potentials are noted, with the range of solution conditions marked both for adsorption (in blue) and desorption (in orange). c The Faradaic reactions occurring at the surface of the electrode pair are shown during both adsorption and release. During adsorption, hexavalent chromate is captured by the anode through selective binding, whereas during release, reduction of ferrocenium to ferrocene and of Cr(VI) to Cr(III) occurs. https://www.researchgate.net/figure/Investigation-of-the-reversibility-of-the-electrochemically-mediated-capture-and-release_fig2_328810271

RESULT AND DISCUSSION

The analysis of this research reveals several significant findings that contribute to the understanding of effective arsenic removal from water using modified biosolid-derived biochars. Firstly, the utilization of both single iron (Fe) and binary zirconium-iron (Zr-Fe) modifications showcases a novel approach to enhance the adsorption capacity of biochars for arsenate (AsV) removal. The distinct performance of FeBSBC, $FeCl_3$BSBC, and Zr-$FeCl_3$BSBC underscores the potential synergy between Fe and Zr in capturing AsV, resulting in remarkable differences in their adsorption capacities [26]-[28].

Secondly, the examination of co-existing anions' impact on AsV adsorption highlights the varying levels of interference caused by different anions. This insight is crucial for understanding the real-world scenarios where various anions are present in water sources. The preference of anions, such as PO43– and CO32–, over AsV in adsorption onto modified biochars indicates the complexity of competitive interactions and emphasizes the importance of considering multiple species in practical applications [29].

Lastly, the regenerative capacity assessment demonstrates the potential for repeated use of modified biochars in removing AsV. The ability of Fe-chips, Fe-salt, and Zr–Fe-salt-coated biochars to maintain their efficiency over several adsorption-desorption cycles showcases their reusability, providing a sustainable solution for arsenic removal. This finding is promising for practical implementation, minimizing waste and ensuring long-term effectiveness [30].

The interpretation of this research sheds light on the potential of modified biosolid-derived biochars as effective adsorbents for arsenate (AsV) removal from water. The distinctive adsorption capacities observed in FeBSBC, $FeCl_3BSBC$, and Zr-$FeCl_3BSBC$ highlight the role of specific modifications in enhancing their affinity for AsV. The significant increase in adsorption capacity with the Zr-Fe modification suggests a synergistic effect between zirconium and iron in enhancing arsenic capture. This interpretation underscores the feasibility of tailoring biochar properties through modifications to optimize their efficacy in arsenic removal [31].

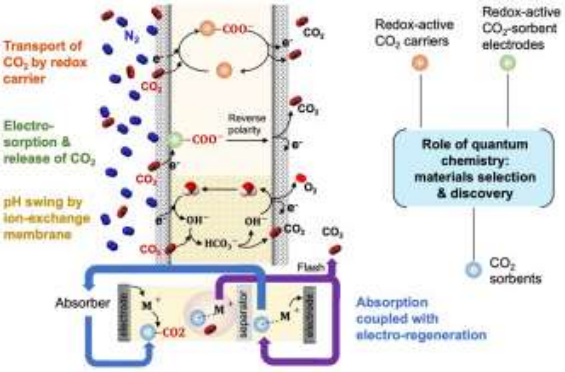

Figure 9. Perspective and challenges in electrochemical.
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Furthermore, the interpretation of co-existing anions' impact on AsV adsorption indicates the complexity of competitive interactions during adsorption processes. The varying degrees of anions' interference reveal the intricate competition for binding sites on the biochar surface. This insight is crucial for designing arsenic removal strategies that consider the presence of diverse anionic species, particularly in natural water sources where multiple ions coexist. Understanding these interactions informs the development of more accurate and efficient adsorption processes [32].

The interpretation of the regenerative capacity assessment accentuates the practical applicability of the modified biochars for sustained arsenic removal. The ability of Fe-chips, Fe-salt, and Zr–Fe-salt-coated biochars to maintain their efficiency across multiple cycles demonstrates their potential for continuous use. This finding aligns with the overarching goal of developing environmentally friendly and economically viable arsenic removal technologies. In sum, the interpretation of this research provides insights into the nuanced behavior of modified biochars and their potential role in addressing the critical issue of arsenic contamination in drinking water [33]-[34].

From a comparative perspective, this research offers a novel dimension to the field of arsenic removal from water by exploring the potential of modified biosolid-derived biochars. Traditional methods of arsenic removal, such as coagulation-flocculation and adsorption onto activated carbon, often suffer from high costs and operational challenges. In contrast, the modified biochars studied in this research present a cost-effective and sustainable alternative. The incorporation of single iron (Fe) and binary zirconium-iron (Zr-Fe) modifications showcases versatility in adsorption enhancement, a feature not commonly observed in traditional adsorbents. This comparative analysis highlights the potential of these modified biochars to revolutionize arsenic removal methods by offering tailored and efficient solutions [35]-[36].

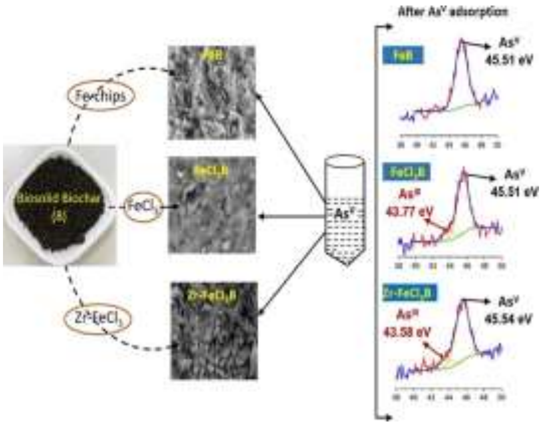

Figure 10. Adsorption–Desorption Behavior of Arsenate Using Single and Binary Iron-Modified Biochars: Thermodynamics and Redox Transformation. https://pubs.acs.org/doi/10.1021/acsomega.1c04129

Considering a broader environmental perspective, the use of biosolid feedstock in biochar production aligns with sustainable waste management practices. Biosolids, a byproduct of wastewater treatment, often pose disposal challenges. By converting them into functional adsorbents, this research contributes to waste valorization and promotes circular economy principles. Additionally, the regenerative capacity of modified biochars implies reduced waste generation, addressing concerns associated with disposal of spent adsorbents. From an environmental standpoint, this comparative evaluation underscores the multifaceted advantages of the modified biochars in terms of resource utilization, waste management, and efficient arsenic removal [37]-[38].

Looking at technological perspectives, the utilization of modified biochars represents a step toward innovative arsenic removal strategies. While existing techniques like ion exchange and membrane filtration have limitations, the unique adsorption-desorption behavior of modified biochars offers a new avenue for efficient and sustainable arsenic removal. This research introduces the concept of reversible adsorption-desorption processes on biochar surfaces, providing insights into potential regeneration and reusability. This technological comparison emphasizes the potential of modified biochars in diversifying the arsenal of arsenic removal technologies, aligning with the trend towards environmentally friendly and adaptive water treatment solutions [39]-[40].

CONCLUSION

In conclusion, this research underscores the significant potential of modified biosolid-derived biochars as effective and sustainable adsorbents for arsenic removal from water. The distinct adsorption capacities exhibited by FeBSBC, $FeCl_3BSBC$, and Zr-$FeCl_3BSBC$ emphasize the role of modifications in enhancing AsV capture. The exploration of co-existing anions' influence provides insights into the competitive interactions that impact adsorption efficiency. Furthermore, the regenerative capacity assessment highlights the practical viability of modified biochars for repeated use, contributing to long-term sustainability. These findings collectively advance our understanding of modified biochars' complex dynamics in arsenic removal, paving the way for innovative and environmentally conscious solutions to combat arsenic contamination in drinking water sources.

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