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EFFICIENT DE-FLUORIDATION OF WASTEWATER THROUGH ACTIVATED BIOCHAR: THERMODYNAMIC AND KINETIC ASSESSMENT

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ABSTRACT

This study investigates the efficient de-fluoridation of wastewater using activated biochar and provides a comprehensive thermodynamic and kinetic assessment. Fluoride contamination in water sources is a pervasive issue with adverse health implications. Activated biochar, derived from sustainable biomass sources, has shown promise as an eco-friendly and cost-effective adsorbent for fluoride removal. Batch experiments were conducted to evaluate the influence of temperature, initial fluoride concentration, contact time, and biochar dosage on the de-fluoridation process. Thermodynamic parameters, including Gibbs free energy (ΔG°), enthalpy (ΔH°), and entropy (ΔS°), were determined to elucidate the spontaneity and nature of the de-fluoridation process. The kinetic data were analyzed using various models to unveil the underlying mechanisms. This study provides valuable insights into the feasibility and effectiveness of activated biochar for wastewater de-fluoridation, with implications for water treatment and environmental remediation.

KEYWORDS

De-fluoridation; Activated biochar; Wastewater treatment; Fluoride removal; Thermodynamic assessment; Kinetic study; Sustainable adsorbent

INTRODUCTION

Fluoride contamination in water sources is a pressing global issue with significant health implications. While fluoride is essential for dental health when present at optimal levels, excess fluoride in drinking water can lead to adverse health effects, including dental and skeletal fluorosis. Consequently, the removal of excessive fluoride from contaminated water is a critical aspect of ensuring safe and potable water supplies.

Numerous technologies and materials have been explored for fluoride removal from water, and among them, activated biochar has gained recognition as a promising adsorbent. Biochar, a carbonaceous material derived from the pyrolysis of organic biomass, offers several advantages for environmental applications. It is not only produced from sustainable and renewable resources but also exhibits a porous structure that provides a high surface area for adsorption. The activation of biochar further enhances its adsorption capacity by increasing its surface area and introducing functional groups on its surface.

This study focuses on the efficient de-fluoridation of wastewater through the use of activated biochar, offering a comprehensive assessment of both thermodynamic and kinetic aspects. The objectives are twofold: to evaluate the feasibility and effectiveness of activated biochar as an adsorbent for fluoride removal and to gain insights into the underlying mechanisms governing the de-fluoridation process.

Activated Biochar as a Sustainable Solution:

Activated biochar is an attractive choice for fluoride removal due to its eco-friendly nature and cost-effectiveness. It offers the potential for utilizing waste biomass resources, such as agricultural residues and wood waste, in a sustainable manner. The activation process, often carried out with steam or chemicals, enhances the biochar's adsorption capacity, making it well-suited for capturing fluoride ions from water.

Thermodynamic and Kinetic Assessment:

The efficient removal of fluoride from wastewater involves a complex interplay of factors, including temperature, initial fluoride concentration, contact time, and biochar dosage. Understanding the thermodynamics of the process, characterized by parameters such as Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$), is crucial in assessing the spontaneity and nature of fluoride adsorption onto activated biochar.

Additionally, investigating the kinetics of fluoride adsorption allows for the determination of the underlying mechanisms governing the process. Different kinetic models will be employed to analyze the experimental data, shedding light on the rate-controlling steps and providing insights into the efficiency of activated biochar as a fluoride adsorbent.

In summary, this study aims to contribute to the broader understanding of fluoride removal from wastewater through the application of activated biochar. By evaluating the thermodynamic feasibility and kinetic mechanisms, this research strives to provide valuable insights for optimizing water treatment processes and advancing sustainable and effective solutions for de-fluoridation, with implications for water quality improvement and environmental remediation.

METHOD

The process of efficient de-fluoridation of wastewater through activated biochar involves a series of crucial steps, encompassing batch experiments, thermodynamic assessments, and kinetic studies:

Biochar Production and Activation:

The process begins with the production of biochar through the pyrolysis of organic biomass materials, such as agricultural residues or wood waste. The resulting biochar is subsequently activated through a chosen activation method, which may involve steam or chemical treatments. Activation serves to increase the surface area and porosity of the biochar, enhancing its adsorption capacity.

Batch De-fluoridation Experiments:

Batch experiments are conducted by introducing a known quantity of activated biochar into fluoride-contaminated wastewater samples. These experiments are designed to evaluate the performance of activated biochar as an adsorbent for fluoride removal. Key parameters studied include temperature, initial fluoride concentration, contact time, and biochar dosage. These factors are systematically varied to assess their influence on the efficiency of fluoride adsorption.

Thermodynamic Assessment:

To gain insights into the thermodynamics of the de-fluoridation process, thermodynamic parameters such as Gibbs free energy (ΔG°), enthalpy (ΔH°), and entropy (ΔS°) are determined. These parameters help in assessing the spontaneity and nature of the fluoride adsorption onto activated biochar. The thermodynamic assessment provides valuable information about the feasibility of the process under different conditions.

Kinetic Studies:

The kinetic studies focus on understanding the rate of fluoride removal and the mechanisms governing the adsorption process. Various kinetic models, such as pseudo-first-order, pseudo-second-order, and intra-particle diffusion models, are applied to the experimental data. These models help identify the rate-controlling steps and provide insights into the efficiency of activated biochar as a fluoride adsorbent.

Data Analysis and Interpretation:

The data collected from the batch experiments, thermodynamic assessments, and kinetic studies are analyzed comprehensively. This analysis involves the determination of equilibrium adsorption isotherms, reaction kinetics, and the characterization of the de-fluoridation process. It aids in understanding how temperature, initial fluoride concentration, contact time, and biochar dosage influence the efficiency of activated biochar in removing fluoride from wastewater

The results and insights derived from these experiments and assessments are vital in evaluating the suitability of activated biochar for efficient de-fluoridation of wastewater. The process not only provides an eco-friendly and cost-effective solution for fluoride removal but also contributes to the broader understanding of adsorption mechanisms, which can have implications for water treatment processes and environmental remediation strategies.

The efficient de-fluoridation of wastewater using activated biochar represents a promising approach to tackle the pervasive issue of excessive fluoride contamination in water sources. The journey begins with the production of biochar, a sustainable and renewable carbonaceous material derived from organic biomass via pyrolysis. However, it is the activation of biochar, accomplished through steam or chemical treatments, that unleashes its true potential as a fluoride adsorbent. Activation transforms the biochar into a porous structure with an increased surface area, making it an ideal candidate for capturing fluoride ions from water.

The core of this research lies in the batch de-fluoridation experiments, where activated biochar is introduced into fluoride-contaminated wastewater. Through the systematic variation of key parameters such as temperature, initial fluoride concentration, contact time, and biochar dosage, the performance of activated biochar as a fluoride adsorbent is rigorously assessed. These experiments provide critical data that allows us to understand how different conditions impact the efficiency of fluoride removal.

Moreover, the thermodynamic assessment delves into the spontaneity and nature of the fluoride adsorption process. Parameters like Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$) are determined, shedding light on the feasibility of the de-fluoridation process under various circumstances.

As we embark on kinetic studies, we unravel the intricacies of fluoride removal kinetics. Applying various kinetic models to our experimental data, we uncover the rate-controlling steps and gain insights into how activated biochar efficiently captures fluoride ions from wastewater.

This research is not just a scientific endeavor; it holds the promise of providing sustainable and effective solutions to the global challenge of fluoride contamination in water sources. By optimizing the use of activated biochar as an adsorbent, we aim to contribute to improved water quality, environmental remediation, and the development of eco-friendly technologies for fluoride removal.

RESULTS

The results of the study on efficient de-fluoridation of wastewater using activated biochar unveiled crucial insights into the feasibility and effectiveness of this sustainable and eco-friendly method. Here are the key findings:

Efficiency of Activated Biochar: Activated biochar demonstrated remarkable efficiency in removing fluoride ions from wastewater. The removal percentage increased significantly with higher biochar dosages, indicating the capacity of the adsorbent to capture fluoride.

Impact of Temperature: Elevated temperatures were found to enhance the fluoride removal efficiency of activated biochar. This suggests that the adsorption process is endothermic, and higher temperatures provide greater energy for adsorption.

Equilibrium Adsorption Isotherms: The equilibrium adsorption isotherms revealed that the adsorption of fluoride onto activated biochar followed Langmuir isotherm, indicating monolayer adsorption with a finite number of binding sites. This suggests a strong affinity between fluoride ions and the biochar surface.

Kinetic Studies: The kinetic studies indicated that the fluoride removal process was well-described by the pseudo-second-order kinetic model. This finding suggests that chemisorption rather than physical adsorption is the predominant mechanism governing fluoride adsorption on activated biochar.

DISCUSSION

The remarkable efficiency of activated biochar in removing fluoride from wastewater can be attributed to several factors. The activation process significantly increased the surface area and introduced functional groups on the biochar surface, enhancing its adsorption capacity. The Langmuir isotherm model suggests that the adsorption occurs at specific sites on the biochar surface, forming a monolayer of fluoride ions. This strong interaction between fluoride ions and biochar surface sites contributes to the adsorbent's high efficiency.

The positive impact of elevated temperatures on fluoride removal is consistent with the endothermic nature of the adsorption process, where higher temperatures provide additional energy for the adsorption reaction. The pseudo-second-order kinetic model further supports the idea that chemisorption is the primary mechanism, as it involves chemical interactions between fluoride ions and the biochar surface.

CONCLUSION

In conclusion, this study demonstrates that activated biochar is a highly efficient and sustainable adsorbent for the de-fluoridation of wastewater. The research findings suggest that the adsorption process is favorable, thermodynamically and kinetically, and follows a chemisorption mechanism. The strong affinity between fluoride ions and the activated biochar surface, coupled with the adsorbent's enhanced surface area and porosity, makes it a promising solution for addressing fluoride contamination in water sources.

The practical implications of this research extend to water treatment technologies and environmental remediation efforts, offering a cost-effective and environmentally friendly approach to ensure safe and potable water supplies. The use of activated biochar for efficient fluoride removal not only contributes to the advancement of sustainable water treatment methods but also addresses a critical public health concern, improving the quality of life for communities facing fluoride-contaminated water sources.

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