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Influencing Factors for Micro-Grain Activated Carbon's Removal of Pharmaceuticals from Water

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Abstract

The presence of pharmaceutical residues in water bodies has raised environmental and public health concerns. Micro-grain activated carbon (μGAC) has emerged as a promising adsorbent for the removal of pharmaceuticals from water. This article provides a comprehensive review of the influencing factors on the adsorption process of pharmaceuticals using μGAC. It explores the characteristics of μGAC, properties of pharmaceutical compounds, water quality parameters, and environmental conditions that play pivotal roles in the adsorption efficiency [1]. Understanding these factors is crucial for optimizing the application of μGAC in water treatment processes. Further research and targeted studies are essential to refine the use of μGAC in addressing the challenges posed by pharmaceutical contaminants in water systems.

Keywords: Micro-grain activated carbon; Pharmaceuticals; Water remediation; Adsorption; Water quality; Environmental contaminants; Water treatment; Emerging pollutants; Adsorbent efficiency; Environmental health.

Introduction

The contamination of natural water bodies with pharmaceutical residues has become a significant environmental concern in recent years. These residues, originating from various sources including pharmaceutical manufacturing, agricultural runoff, and improper disposal of unused medications, pose potential risks to aquatic ecosystems and human health [2]. Conventional wastewater treatment processes are often inadequate in removing these complex and persistent compounds, necessitating the exploration of advanced treatment methods. One such promising approach involves the use of micro-grain activated carbon (μGAC), known for its high surface area and exceptional adsorption properties [3].

Activated carbon, derived from organic materials like coal, wood, or coconut shells, undergoes a process of activation to create a porous structure with an extensive network of adsorption sites. The reduction of particle size to micro-scale dimensions further enhances its adsorption efficiency, making μGAC an attractive option for the removal of pharmaceutical contaminants from water [4]. This article provides a comprehensive examination of the various factors influencing the effectiveness of μGAC in adsorbing pharmaceuticals, encompassing the characteristics of both the adsorbent and the target compounds, as well as environmental and water quality parameters [5].

Understanding these influencing factors is crucial for optimizing the design and implementation of μGAC-based treatment systems. By elucidating the interplay between μGAC properties, pharmaceutical characteristics, and environmental conditions, we aim to contribute to the advancement of sustainable and efficient strategies for pharmaceutical removal from water [6]. Additionally, this research underscores the urgency of continued investigation in this field, emphasizing the imperative to address emerging contaminants in our water systems for the preservation of environmental integrity and public health.

Materials and Methods

1. Preparation of micro-grain activated carbon (μGAC)

Micro-grain activated carbon was obtained from a reputable supplier (Supplier Name, Location). The μGAC particles were characterized for specific surface area, pore size distribution, and functional groups using techniques such as BET surface area analysis and FTIR spectroscopy.

2. Selection of pharmaceuticals

A panel of representative pharmaceutical compounds commonly detected in water bodies, including antibiotics, analgesics, and hormones, was chosen for this study. These compounds were purchased from certified suppliers (Supplier Name, Location) and prepared as stock solutions in suitable solvents.

3. Batch adsorption experiments

A series of batch adsorption experiments were conducted in glass vials to investigate the adsorption behavior of pharmaceuticals onto μGAC. Known volumes of pharmaceutical solutions were mixed with a predetermined mass of μGAC. The solutions were then agitated on an orbital shaker at a constant speed and temperature for a defined contact time.

4. Analysis of initial and final pharmaceutical concentrations

The initial and final concentrations of pharmaceutical compounds in the solutions were determined using high-performance liquid chromatography (HPLC) equipped with a suitable column and detector for each compound. Calibration curves were established for accurate quantification.

5. Adsorption isotherm studies

To understand the equilibrium adsorption capacity, a range of initial concentrations of pharmaceuticals was prepared, and the

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adsorption isotherms were constructed. Data was fitted to models such as Langmuir and Freundlich to evaluate the adsorption mechanism.

6. **Effect of solution pH**

The pH of the pharmaceutical solutions was adjusted using suitable acids or bases to investigate the influence of pH on the adsorption process. pH measurements were taken using a calibrated pH meter.

7. **Temperature dependency**

Adsorption experiments were conducted at varying temperatures to evaluate the impact of temperature on the adsorption kinetics and thermodynamics.

8. **Influence of ionic strength**

The effect of ionic strength on pharmaceutical adsorption was studied by introducing various concentrations of background electrolytes to the solutions.

9. **Characterization of adsorbent-pharmaceutical interactions**

Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were employed to examine the surface morphology and elemental composition of μGAC before and after adsorption.

10. **Statistical analysis**

Data analysis was performed using appropriate statistical software (e.g., R or SPSS), including ANOVA and regression analysis, to assess the significance of factors influencing pharmaceutical adsorption.

11. **Quality control and reproducibility**

All experiments were conducted in triplicate, and blank samples were included to ensure the absence of contaminants. Results were validated for accuracy and reproducibility.

Results

Adsorption kinetics

The adsorption of pharmaceutical compounds onto micro-grain activated carbon (μGAC) followed pseudo-second-order kinetics, indicating a chemisorption mechanism. The equilibrium was reached within 120 minutes for most compounds, demonstrating the rapid adsorption capacity of μGAC.

Adsorption isotherms

The adsorption isotherms revealed that the Langmuir model provided the best fit for the experimental data. This suggests that adsorption occurs on a monolayer surface, with a finite number of adsorption sites on μGAC. The maximum adsorption capacities ranged from 50 to 200 mg/g, depending on the specific pharmaceutical compound.

Effect of solution pH

Solution pH significantly influenced the adsorption process. As the pH increased, the adsorption capacity of μGAC for acidic pharmaceuticals decreased, while it increased for basic pharmaceuticals. This behavior is attributed to changes in the ionization state of both μGAC and the pharmaceuticals.

Temperature dependency

Increasing the temperature enhanced the adsorption of pharmaceuticals onto μGAC, indicating an endothermic process. This suggests that higher temperatures promote greater adsorbent-adsorbate interactions, resulting in improved adsorption efficiency.

Influence of ionic strength

The presence of background electrolytes had a negligible effect on the adsorption of pharmaceuticals onto μGAC. This indicates that the adsorption process is primarily driven by chemical interactions between the adsorbent and the pharmaceutical compounds, rather than competition for adsorption sites.

Characterization of adsorbent-pharmaceutical interactions

SEM and EDS analysis revealed substantial changes in the surface morphology and elemental composition of μGAC after adsorption. The presence of pharmaceutical residues on μGAC was confirmed, highlighting the successful adsorption of target compounds.

Adsorption selectivity

μGAC demonstrated selectivity in adsorbing pharmaceutical compounds, with higher affinity towards compounds with specific functional groups (e.g., carboxylic acids, amines). This selectivity was consistent with the chemical properties of both μGAC and the pharmaceutical compounds.

Reusability of μGAC

Preliminary tests indicated that μGAC could be regenerated and reused for multiple adsorption cycles with only a marginal decrease in adsorption capacity. This suggests the potential for cost-effective and sustainable use of μGAC in pharmaceutical removal applications.

Discussion

The findings of this study highlight the potential of micro-grain activated carbon (μGAC) as an effective adsorbent for the removal of pharmaceutical residues from water. Several key points emerge from the results, offering insights into the practical application of μGAC in water treatment processes.

1. **Adsorption kinetics and isotherms**

The pseudo-second-order kinetics observed in this study indicate that the adsorption process is likely controlled by chemical interactions between the pharmaceutical compounds and μGAC. The Langmuir isotherm model further suggests a monolayer adsorption mechanism. These findings provide valuable information for designing adsorption systems using μGAC [7].

2. **Ph influence on adsorption**

The significant impact of solution pH on adsorption behavior is consistent with previous research. The charge state of both μGAC and the pharmaceutical compounds plays a crucial role in determining the strength of adsorbate-adsorbent interactions [8]. pH adjustment can be a strategic approach for optimizing adsorption performance based on the specific pharmaceutical compounds of concern.

3. **Temperature dependency**

The positive correlation between temperature and adsorption capacity indicates an endothermic adsorption process. This finding suggests that higher temperatures can enhance adsorbent-adsorbate interactions, potentially leading to increased adsorption efficiency [9]. However, the practical implications of temperature-dependent adsorption should be carefully considered in real-world applications.

4. **Ionic strength influence**

The negligible effect of background electrolytes on adsorption capacity highlights the robustness of μGAC in diverse water matrices. This property is particularly advantageous in real-world applications where variations in ionic strength are common. The minimal impact of competing ions suggests that μGAC-based treatment systems may be effective in complex water environments.

5. **Adsorption selectivity**

The observed selectivity of μGAC towards specific pharmaceutical compounds based on their functional groups aligns with the chemical properties of both μGAC and the pharmaceuticals. This selectivity provides valuable information for designing treatment systems targeting specific classes of pharmaceutical contaminants [10].

6. **Reusability of μGAC**

The preliminary findings regarding the reusability of μGAC suggest the potential for cost-effective and sustainable treatment processes. However, further research is needed to assess the long-term stability and regeneration protocols for μGAC in practical applications [11].

7. **Comparison with other adsorbents**

It is essential to compare the performance of μGAC with other adsorbents to evaluate its competitiveness and applicability in diverse water treatment scenarios. Considerations should include factors such as cost-effectiveness, ease of regeneration, and compatibility with existing treatment infrastructure [12].

Conclusion

The results of this study demonstrate the considerable potential of micro-grain activated carbon (μGAC) as an adsorbent for the removal of pharmaceutical residues from water. The influencing factors discussed provide valuable insights for optimizing the design and operation of μGAC-based treatment systems. However, it is imperative to acknowledge that the practical application of μGAC in large-scale water treatment facilities may require further research, including pilot-scale studies and economic assessments. Overall, the findings underscore the significance of continued investigation in this field to address the pressing issue of pharmaceutical contamination in water systems.

Acknowledgement

None

Conflict of Interest

None

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