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SYNTHESIS AND APPLICATION OF POLYVINYL CHLORIDE-BASED SORBENTS FOR HEAVY METAL ION REMOVAL FROM INDUSTRIAL WASTEWATER

Kh.Kh.Turaev [1], L.U.Bozorov [2], Kh.E.Eshmurodov [3]

[1] Termez State University, Barkamol Avlod Street 43, Termez, Uzbekistan
e-mail: hhturaev@rambler.ru:
[2]Termez State Pedagogical Institute, At-Termiziy Street 1, Termez, Uzbekistan
e-mail: lutfullabozorov@gmail.com
[3] Tashkent Research Institute of Chemical Technology. Tashkent, Uzbekistan
e-mail: khurshideshmurodov@gmail.com

Abstract:

This research explores the synthesis of polyvinyl chloride (PVC)-based sorbents modified with various organic compounds, including diethylamine, monoethanolamine, and sodium diethyldithiocarbamate. These sorbents demonstrate high efficacy in the sorption of heavy metal ions such as Cu(II), Cd(II), Zn(II), and Ag(I). The study presents the physicochemical analysis of these sorbents, including IR-spectroscopy and thermal analysis, and evaluates their performance in static and dynamic conditions. The results show that the modified PVC sorbents are highly effective in removing toxic metal ions from industrial wastewater, making them a promising solution for environmental remediation.

Keywords: Polyvinyl chloride, sorbents, heavy metal removal, wastewater treatment, modification, environmental protection.

Introduction

The increasing industrial demand and growing environmental concerns have led to the development of advanced materials capable of efficiently removing toxic substances from wastewater. Sorbents, especially those based on synthetic polymers like polyvinyl chloride (PVC), are gaining attention for their ability to selectively adsorb heavy metal ions from industrial wastewater. PVC is known for its high chemical stability and mechanical strength, making it an ideal candidate for modification into functional sorbents.

Modified PVC-based sorbents, particularly those functionalized with nitrogen and sulfur-containing compounds such as amines and dithiocarbamates, exhibit enhanced sorption capacities for metal ions. This research aims to synthesize and evaluate PVC-based sorbents for the removal of heavy metals, such as copper (Cu), cadmium (Cd), zinc (Zn), and silver (Ag), from wastewater, providing an eco-friendly and cost-effective solution to pollution control.

Polyvinyl chloride (PVC) is widely recognized for its versatility and durability, making it one of the most significant polymers in various industries such as construction, automotive, and pharmaceuticals. The modification of PVC, particularly for sorbent production, has been the focus of numerous studies due to its potential to improve sorption properties and enhance the polymer's performance in industrial applications.

PVC is typically modified using reactive compounds such as amines, resulting in materials with enhanced physical and chemical properties. These modifications are essential for the development of new functional materials, including sorbents with improved selectivity for metal ion adsorption. The chemical structure of PVC allows it to form complexes with various reagents, enhancing its ability to act as an efficient sorbent. Modified PVC sorbents, particularly those involving amine groups, have shown high effectiveness in absorbing heavy metal ions, making them suitable for environmental applications such as wastewater treatment.

The modification process often involves introducing functional groups that improve the material's ability to interact with specific ions. For instance, diethylenetriamine and monoethanolamine have been used to modify PVC, leading to sorbents with significantly enhanced capacity for binding metal ions like cadmium, copper, and silver. These modifications not only increase the sorbent's efficiency but also provide stability under varying environmental conditions, which is crucial for practical applications in hydrometallurgy and water purification.

Furthermore, the study of PVC's physicochemical properties reveals its robustness against harsh chemicals, contributing to its wide range of applications. It is highly resistant to acids, alkalis, and organic solvents, making it ideal for producing durable materials that can withstand aggressive environments. Additionally, the polymer's polar nature and partially crystalline structure facilitate its interaction with modifying agents, which is critical for enhancing its sorption and mechanical properties.

One of the main advantages of using PVC-based materials is the ability to modify them through relatively simple chemical processes. These modifications enable the production of sorbents with tailored characteristics, such as increased ion exchange capacity and specific selectivity for certain metal ions. The development of these advanced materials is crucial for addressing modern industrial challenges, particularly in fields that require efficient separation and purification technologies

2. Materials and Methods

2.1. Materials

The PVC used in this study was obtained from commercial suppliers. The following modifiers were employed: diethylamine (DEA), monoethanolamine (MEA), and sodium diethyldithiocarbamate (DEDC). The metal ions used for sorption experiments were sourced from standard laboratory solutions containing Cu(II), Cd(II), Zn(II), and Ag(I).

2.2. Synthesis of PVC-Based Sorbents

The synthesis of modified PVC sorbents involved the following steps:

Preparation of PVC Solution: PVC was dissolved in an appropriate solvent to form a homogeneous solution.

Addition of Modifiers: The selected organic modifiers were added to the PVC solution at varying concentrations. The mixture was stirred to ensure proper dispersion.

Crosslinking and Gelation: The mixture was subjected to heat to facilitate crosslinking, leading to gel formation.

Molding and Drying: The gel was poured into molds and allowed to cure at room temperature. The resulting sorbents were then dried and ground to a fine powder for characterization and testing.

2.3 Physicochemical Characterization

The synthesized sorbents were characterized using:

IR Spectroscopy: To identify functional groups and confirm modifications.

Thermal Analysis: Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were performed to evaluate thermal stability and degradation patterns.

2.4. Sorption Experiments

2.4.1. Static Sorption Tests

Static adsorption tests were conducted by mixing a known weight of the sorbent with a fixed concentration of metal ion solution in a series of glass flasks. The flasks were shaken at a constant

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temperature for a predetermined period. After equilibration, samples were filtered, and the residual metal ion concentrations were measured using atomic absorption spectrometry (AAS).

2.4.2. Dynamic Sorption Tests

Dynamic tests were carried out using a column packed with the modified sorbents. A continuous flow of metal ion solution was passed through the column, and samples were collected at regular intervals. The sorption capacity was assessed by calculating the breakthrough curves and the amount of metal ions removed.

3. Results (continued)

3.1. Physicochemical Characterization (continued)

The thermal analysis results showed that the sorbent modified with sodium diethyldithiocarbamate (DEDC) had the highest thermal stability, with degradation starting at 300°C, whereas sorbents modified with diethylamine (DEA) and monoethanolamine (MEA) exhibited degradation at lower temperatures, around 250°C. These results indicate that the choice of modifier affects the thermal properties of the sorbents, making DEDC-modified PVC sorbents more suitable for high-temperature applications.

3.2. Sorption Capacity of Modified PVC Sorbents

The sorption capacities of the modified PVC sorbents for heavy metal ions (Cu^{2+}, Cd^{2+}, Zn^{2+}, and Ag^{+}) were evaluated in both static and dynamic conditions. The results from the static sorption tests showed that the sorbents exhibited different adsorption capacities depending on the type of metal ion and the modifier used.

Sorbent Modifier	**Cu^{2+} Sorption Capacity (mg/g)**	**Cd^{2+} Sorption Capacity (mg/g)**	**Zn^{2+} Sorption Capacity (mg/g)**	**Ag^{+} Sorption Capacity (mg/g)**
Diethylamine (DEA)	45.2	38.5	41.8	48.6
Monoethanolamine (MEA)	50.1	42.3	44.7	52.4
Sodium Diethyldithiocarbamate (DEDC)	55.8	47.9	50.2	60.3

From these results, it was evident that the DEDC-modified PVC sorbents exhibited the highest sorption capacity for all metal ions tested, particularly for Ag^{+} and Cu^{2+} ions. This can be attributed to the strong complex-forming abilities of DEDC, which enhances the binding of metal ions to the sorbent surface.

3.3. Dynamic Sorption Tests

The breakthrough curves obtained from the dynamic sorption tests showed that DEDC-modified PVC sorbents had the highest retention time for metal ions compared to the other sorbents. The total metal ion removal efficiency was also significantly higher in dynamic conditions, especially for Cu^{2+} and Ag^{+}, where over 95% of the ions were removed from the solution during the dynamic flow tests.

Sorbent Type	**Cu^{2+} Sorption Capacity (mg/g)**	**Cd^{2+} Sorption Capacity (mg/g)**	**Zn^{2+} Sorption Capacity (mg/g)**	**Ag^{+} Sorption Capacity (mg/g)**

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PVC + DEA (Diethylamine)	18.5	12.3	10.1	15.7
PVC + MEA (Monoethanolamine)	20.1	14.7	11.5	17.9
PVC + DEDC (Sodium diethyldithiocarbamate)	22.8	16.3	14.2	21.4

The DEDC-modified PVC sorbents showed the highest sorption capacity for all metal ions, with significant affinity for Ag^{+} and Cu^{2+}. This can be attributed to the strong complexation ability of DEDC with metal ions. The DEA-modified sorbents demonstrated moderate sorption capacities, while the MEA-modified sorbents showed higher performance than DEA-modified sorbents but lower than those modified with DEDC.

3.3 Static Sorption Performance

The static sorption experiments revealed that equilibrium was reached within 4 hours for all sorbents, with no significant changes in sorption capacity observed beyond this time. The sorption isotherms followed a typical Langmuir adsorption model, indicating monolayer adsorption on a homogeneous surface. The maximum sorption capacity (q_max) values derived from the Langmuir isotherms further confirmed the superior performance of DEDC-modified sorbents.

3.4. Dynamic Sorption Performance

In dynamic conditions, the breakthrough curves showed that DEDC-modified PVC sorbents had the longest breakthrough time, indicating a higher retention capacity for metal ions under continuous flow conditions. The breakthrough times for DEA and MEA-modified sorbents were shorter, correlating with their lower sorption capacities. The dynamic sorption capacity was highest for Ag^{+}, followed by Cu^{2+}, Cd^{2+}, and Zn^{2+} ions, similar to the static tests.

4. Discussion

The results of this study clearly demonstrate that modifying PVC with specific organic compounds significantly enhances its sorption capacity for heavy metal ions. The improved performance of DEDC-modified sorbents can be attributed to the sulfur-containing functional groups, which are known to form strong complexes with metal ions such as Ag^{+} and Cu^{2+}. These findings suggest that the choice of modifier plays a crucial role in determining the sorbent's efficacy.

The physicochemical analysis also highlighted the differences in thermal stability among the modified sorbents. The higher thermal stability of DEDC-modified sorbents makes them suitable for applications in environments where higher temperatures may be encountered, such as in industrial wastewater treatment facilities.

The adsorption mechanism, as inferred from the Langmuir model, suggests that metal ion binding occurs through monolayer adsorption on the surface of the modified PVC sorbents. The sorbents' high selectivity for Ag^{+} and Cu^{2+} ions indicates potential for applications in the recovery of valuable metals from industrial effluents, in addition to environmental cleanup.

The dynamic sorption tests further confirmed the practical applicability of these sorbents in continuous flow systems, where extended breakthrough times are desirable for efficient wastewater treatment. The superior performance of DEDC-modified sorbents in these tests points to their potential use in industrial-scale processes.

5. Conclusion

This study successfully synthesized and characterized PVC-based sorbents modified with diethylamine (DEA), monoethanolamine (MEA), and sodium diethyldithiocarbamate (DEDC). Among the modified sorbents, the DEDC-modified PVC sorbent exhibited the highest sorption capacity for heavy metal ions such as Cu^{2+}, Cd^{2+}, Zn^{2+}, and Ag^{+}. The sorption isotherms indicated that the adsorption followed a monolayer mechanism, with DEDC-modified sorbents providing the best performance in both static and dynamic conditions.

The results of this research indicate that modified PVC-based sorbents are promising materials for the removal of heavy metal ions from industrial wastewater. Future studies should explore the regeneration and reuse of these sorbents, as well as their long-term stability in real-world wastewater treatment applications.

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