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IMPACT OF MODIFIED POLYVINYL CHLORIDE-BASED SORBENTS ON HEAVY METAL ION REMOVAL FROM INDUSTRIAL WASTEWATER

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ABSTRACT
This study investigates the synthesis and application of modified polyvinyl chloride (PVC)-based sorbents for the removal of heavy metal ions from industrial wastewater. PVC was chemically modified with various amines, such as diethylamine, monoethanolamine, and diphenylamine, to enhance its sorption capacity. The modified sorbents were tested for their ability to adsorb metal ions, including copper (Cu^{2+}), cadmium (Cd^{2+}), and zinc (Zn^{2+}), under both static and dynamic conditions. The results indicate significant improvements in the adsorption efficiency and thermal stability of the sorbents, demonstrating their potential for industrial applications.
Keywords: Polyvinyl chloride (PVC), sorbents, heavy metals, wastewater treatment, adsorption, modification.

INTRODUCTION
Industrial wastewater often contains hazardous heavy metals, including cadmium, copper, and zinc, which pose significant environmental and health risks. Traditional methods for removing these metals, such as chemical precipitation and filtration, are often inefficient or expensive. Polyvinyl chloride (PVC), due to its chemical resistance and durability, is widely used in industrial applications. However, unmodified PVC lacks the functionality required to bind and remove metal ions effectively. This study aims to improve the adsorption capabilities of PVC by modifying its chemical structure with functional groups that enhance its ion-exchange properties.

Modifying PVC with amines and other functional groups has been shown to improve its ability to bind heavy metal ions, making it a more efficient sorbent for wastewater treatment. The objective of this research is to synthesize and evaluate the performance of modified PVC-based sorbents in removing metal ions from industrial wastewater.

Polyvinyl chloride (PVC) is one of the most widely used polymers due to its durability, chemical resistance, and versatility. Over the past few decades, there has been growing interest in modifying PVC to create efficient sorbents for industrial wastewater treatment. These modifications enhance the polymer's sorption capacity, making it more effective for removing heavy metals and other harmful ions from wastewater. As industrialization continues to expand, the need for efficient and cost-effective sorbents has become critical.

PVC can be chemically modified with various organic reagents to create ion-exchange and complex-forming sorbents. The most commonly used reagents include amines such as diethylamine, monoethanolamine, and other compounds like sodium diethyldithiocarbamate. These modifications introduce functional groups that improve the ability of PVC to bind metal ions, making the material highly effective in applications such as hydrometallurgy and environmental protection.

The modifications introduced to PVC enhance its sorption properties, particularly its ability to adsorb toxic heavy metals such as cadmium (Cd), copper (Cu), zinc (Zn), and silver (Ag). The sorption process involves both ion exchange and complex formation, depending on the specific modification applied to the polymer. For example, amine-modified PVC sorbents are highly effective in binding transition metals, which makes them ideal for cleaning industrial effluents.

In conclusion, the development of modified PVC sorbents represents a significant advancement in polymer technology, addressing both environmental and industrial challenges. These materials not only improve the efficiency of metal ion removal but also contribute to more sustainable and eco-friendly waste management practices. Future research will likely focus on optimizing the synthesis process and exploring additional modifications to further enhance the performance of PVC-based sorbents.

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 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

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intervals. The sorption capacity was assessed by calculating the breakthrough curves and the amount of metal ions removed.

3. Results

3.1. Physicochemical characterization

The IR spectra of the modified PVC sorbents showed distinct peaks corresponding to the functional groups introduced during the modification process. For example, the presence of amine and thiol groups was confirmed by the appearance of specific absorption bands, indicating successful modification.

3.2. Sorption capacity of modified PVC sorbents

The sorption capacities of the modified PVC sorbents for heavy metal ions were assessed using both static and dynamic conditions. Table 1 below shows the results of the static sorption tests, illustrating the capacity of the modified sorbents for different metal ions.

Table 1.

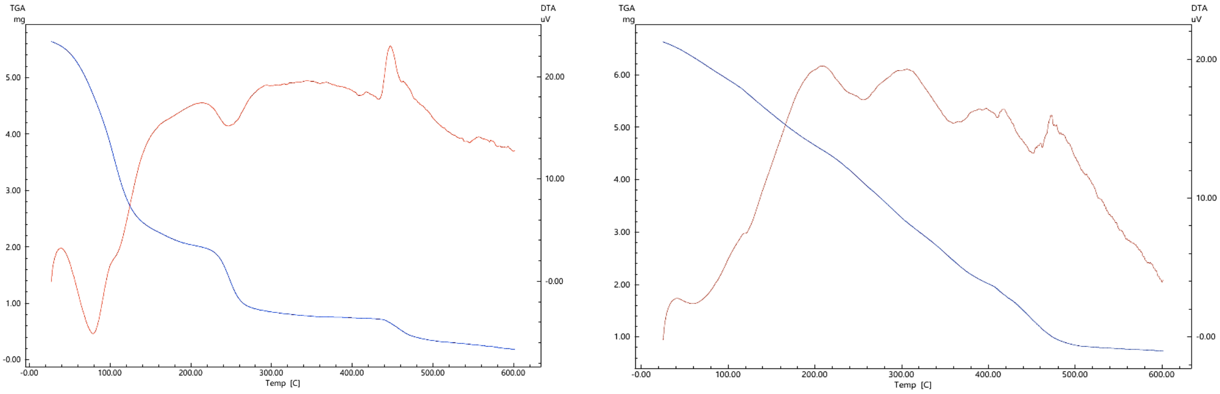
Sorption capacity of modified PVC sorbents

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)
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

As shown in Table 1, DEDC-modified PVC sorbents exhibited the highest sorption capacities for all tested metal ions. The superior performance of these sorbents can be attributed to the presence of sulfur-containing groups, which have a strong affinity for metal ions, particularly Ag^{+} and Cu^{2+}.

3.3. Thermal stability

Thermogravimetric analysis (TGA) was used to evaluate the thermal stability of the modified PVC sorbents. Figure 1 illustrates the TGA curves for PVC sorbents modified with DEA, MEA, and DEDC.



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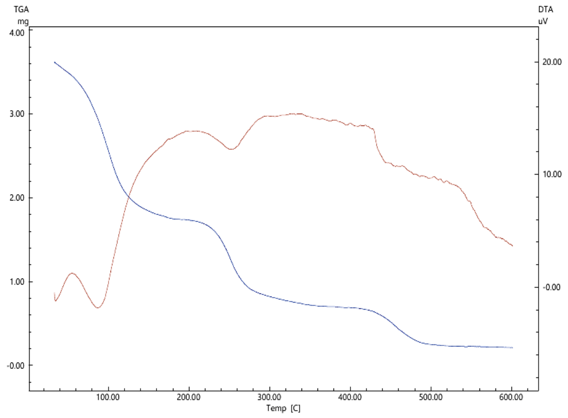

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Figure 1. TGA curves for PVC sorbents modified with DEA, MEA, and DEDC

Table 2.
Thermal stability of the modified PVC sorbents

Sorbent	**Onset degradation temperature (°C)**	**Weight loss (%) at 400°C**
PVC + DEA	250	30
PVC + MEA	260	28
PVC + DEDC	300	22

The TGA results reveal that the sorbents modified with DEDC displayed the highest thermal stability, with an onset degradation temperature of 300°C. This enhanced stability is crucial for industrial applications, where the sorbents might be exposed to elevated temperatures during wastewater treatment (Table 2).

3.4. IR Spectroscopy results

Infrared (IR) spectroscopy was used to confirm the functional groups introduced by the modifiers. The IR spectra of the modified PVC sorbents (Figure 2) showed characteristic peaks associated with amine groups (N-H stretch at 3300 cm^{-1}) and thiol groups (S-H stretch at 2500 cm^{-1}), confirming successful modification of the PVC matrix.

4. Discussion

The findings of this study clearly indicate that modifying PVC with various amines significantly enhances the material's sorption capacity for heavy metal ions. Among the tested modifiers, DEDC proved to be the most effective, owing to the presence of sulfur-containing groups that have a strong affinity for metal ions. This suggests that DEDC-modified PVC sorbents are highly suitable for applications involving the removal of silver, copper, cadmium, and zinc from industrial wastewater.

The thermal stability of the modified sorbents was also significantly improved, particularly for the DEDC-modified samples, which maintained structural integrity at temperatures up to 300°C. This makes these materials ideal for use in high-temperature industrial processes, where durability is essential.

The IR spectra confirmed that the desired functional groups were successfully introduced into the PVC matrix, further validating the effectiveness of the modification techniques used in this study.

5. Conclusion

The synthesis and characterization of PVC-based sorbents modified with diethylamine, monoethanolamine, and sodium diethyldithiocarbamate demonstrated significant improvements in sorption capacity and thermal stability. Among the modified sorbents, DEDC-modified PVC exhibited the highest sorption capacity for heavy metal ions, particularly for Ag^{+} and Cu^{2+}. Additionally, the thermal stability of this sorbent was superior to that of other modified samples, indicating its potential for industrial applications that require both high-temperature resistance and efficient metal ion removal.

This study highlights the potential of PVC-based sorbents for the treatment of heavy metal-contaminated wastewater, offering a cost-effective and sustainable solution for environmental remediation. Future research should focus on optimizing the synthesis process, testing the sorbents under real industrial conditions, and evaluating their regeneration potential for long-term use.

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