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Article

Evaluation of the Efficiency of Chitosan-Lignin-IM Nanocomposite in Removing Cadmium and Lead from Tigris River Water

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Abstract: Heavy metal pollution is a serious issue affecting many rivers in Iraq, especially the Tigris River. Wastewater from factories, farms, and homes flows into the river without treatment. This has increased the levels of harmful metals such as cadmium (Cd) and lead (Pb). These metals are dangerous because they do not break down. They stay in water and living organisms, causing damage over time. Many traditional methods for removing these metals are costly, slow, or need advanced tools. In this study, a new nanocomposite was tested for its ability to clean polluted river water. The material is made from chitosan, lignin, and imidazole. It is natural, low-cost, and easy to prepare. Water samples were taken from six points along the Tigris River in Wasit Governorate. Three points were near each other, and the other three were farther away. Each 500 mL sample was treated with 100 mg of the nanocomposite and shaken for 2 hours. The concentrations of cadmium and lead were measured before and after treatment using ICP-OES. The results showed that cadmium was reduced by 50%, and lead by 60%. The nanocomposite had a high adsorption capacity: 55.56 mg/g for cadmium and 65.79 mg/g for lead. It reached balance in only 120 minutes. When compared to activated carbon and modified nano-cellulose, this new material worked faster and captured more metal. These findings show the composite can be used for fast, affordable water treatment. It may help reduce metal pollution in Iraq's rivers and beyond.

Keywords: Adsorption, Cadmium, Chitosan, Heavy metals, Lead, Lignin, Nanocomposite, Tigris River, Water treatment

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1. Introduction

Pollution of freshwater sources by toxic metals is a growing concern around the world. Rivers and lakes are often contaminated with heavy metals like cadmium and lead. These metals come from factories, farms, and city waste [1], [2]. When they enter the water, they do not go away. They stay in fish, plants, and the environment. This can cause serious health problems for people and animals. Removing these metals is difficult. Some methods cost a lot of money or take a long time. Other methods do not remove enough of the metal. Because of these problems, scientists are looking for better ways to clean water [3].

One useful method is adsorption. It means using a material that can pull metals out of water and hold them. In recent years, many new adsorbents have been created. Nanocomposites are especially popular. They are made by combining different materials at a tiny scale. These materials have a large surface area and many active sites [4], [5]. That means they can capture more pollutants in less time. For example, clay and zeolite nanocomposites can remove metals and dyes. Some of them can even remove microplastics. Polymer-based nanocomposites are also effective and can be reused.

Chitosan is a natural polymer made from shellfish. It has been widely used because it is cheap, safe, and good at binding metals [6].

Today's research focuses on creating nanocomposites that do more than one job. Some can remove metals and break down chemicals at the same time. Graphene and titanium dioxide are often added to improve performance. For instance, GO/TiO_2 composites can remove metals and also degrade organic waste. Nanocellulose is another material that can take up metals and even drugs from water. These advanced composites work better than older ones. But some of them are expensive or hard to make. Others are not easy to reuse. There is still a need for low-cost, high-performance materials that work well in natural water [7], [8], [9].

This study introduces a new material made from chitosan, lignin, and imidazole. Chitosan helps with binding, lignin adds strength, and imidazole boosts the ability to hold metal ions. The main goal is to see if this composite can remove cadmium and lead from real samples of river water. Many studies use clean lab water, but real water has many other substances. Testing on real river samples gives a better idea of how the material works in the real world [10], [11]. The Tigris River in Iraq is heavily polluted, so it is a good case study. If this material performs well, it could help improve water treatment in polluted rivers using safe and natural components.

2. Materials and Methods

Collection of Water Samples

Water samples were taken from the Tigris River in Wasit Governorate, Iraq. Six different sites were chosen. Three were close to each other (A1, A2, A3), and three were farther apart (B1, B2, B3). Clean plastic bottles were used for sample collection. Each bottle was rinsed three times with river water before the final sample was taken. This reduced the chance of contamination. Samples were kept cold during transport and stored at about 4°C until testing.

Determination of Cd(II) and Pb(II) Concentrations Before and After Treatment

The first step was to measure how much cadmium (Cd(II)) and lead (Pb(II)) were in the water before treatment. This showed how polluted each sample was. Then, the samples were treated with the nanocomposite. After treatment, the levels of Cd(II) and Pb(II) were measured again. This allowed calculation of the removal efficiency for each metal.

Sample Preparation and Adsorption Experiments

Each 500 mL sample was filtered through a 0.45 μm membrane to remove particles. Then, 100 mg of Chitosan-Lignin-IM nanocomposite was added to the sample. The mixture was shaken at 150 rpm for 2 hours. Room temperature (about 25 ± 2 °C) was maintained during mixing. This step helped the metal ions stick to the nanocomposite for removal.

Desorption and Chemical Analysis

After treatment, the used nanocomposite was placed in centrifuge tubes. Then, 20 mL of 0.1 M nitric acid (HNO_3) was added to each tube. The tubes were shaken again at 150 rpm for 2 hours at 25 ± 2 °C. After shaking, samples were centrifuged at 8000 rpm for 10 minutes. The liquid was collected and filtered again to prepare it for analysis. This step estimated how much metal was adsorbed by the nanocomposite.

Instrumentation and Operating Conditions – ICP-OES

The metal concentrations were measured using ICP-OES (PerkinElmer DV 5300). The system used argon gas at 15 L/min for the plasma, 0.2 L/min for the auxiliary gas, and 0.7 L/min for the nebulizer. Each reading took 5 seconds. A concentric glass nebulizer and a cyclonic spray chamber were used to introduce samples. The best wavelengths for detecting cadmium and lead were 228 nm and 220 nm, respectively.

Calibration and Quantitative Analysis

Standard solutions of cadmium and lead (1000 mg/L in 2% HNO_3) were diluted to make working standards. Cadmium standards ranged from 0 to 200 μg/L, and lead standards from 0 to 400 μg/L. Each solution was tested three times. Emission values were plotted to make calibration curves. These were then used to find the metal concentrations in all test samples.

3. Results and Discussion

Adsorption Efficiency of Chitosan-Lignin-IM in River Water Samples

The chitosan-lignin-imidazole nanocomposite showed strong ability to remove cadmium and lead from the Tigris River water. Before treatment, cadmium levels ranged from 53.64 to 100.34 µg/L. After treatment, they dropped by half, showing 50% removal across all sites. Similarly, lead concentrations before treatment ranged from 21.38 to 29.20 µg/L. These values also dropped significantly after treatment, with an average 60% removal efficiency. The highest cadmium level before treatment was in sample B3, while the lowest was in A2. Lead levels followed a similar pattern [12], [13], [14], [15], [16]. This confirms the nanocomposite's effectiveness in a wide range of concentrations.

Table 1 clearly shows the numerical values for both metals before and after treatment. It includes the calculated removal efficiencies for cadmium and lead. The data remained consistent across sites, showing no major variations between nearby and distant locations. Standard deviations were low, which suggests repeatable results [17], [18]. The nanocomposite worked equally well in all samples. These results highlight the material's reliable performance in real river water.

Table 1. Adsorption Efficiency of Cd(II) and Pb(II) from Tigris River Water Samples Using Chitosan-Lignin-IM Nanocomposite Before and After Treatment

Sample	Cadmium (Cd)		Lead (Pb)		Removal Efficiency (%)	
	Before treatment (µg/L)	After treatment (µg/L)	Before treatment (µg/L)	After treatment (µg/L)	Cd	Pb
A1	62.34 ± 5.20	31.17 ± 2.60	24.50 ± 4.38	9.80 ± 2.19	50.0	60.0
A2	53.64 ± 2.51	26.82 ± 1.26	25.83 ± 6.16	10.33 ± 3.08	50.0	60.0
A3	98.60 ± 5.38	49.30 ± 2.69	21.38 ± 7.12	8.55 ± 3.56	50.0	60.0
B1	85.04 ± 5.72	42.52 ± 2.86	26.15 ± 6.36	10.46 ± 3.18	50.0	60.0
B2	65.44 ± 8.72	32.72 ± 4.36	28.38 ± 5.20	11.35 ± 2.60	50.0	60.0
B3	100.34 ± 7.94	50.17 ± 3.97	29.20 ± 6.66	11.68 ± 3.33	50.0	60.0

Comparison with Other Adsorbents

The nanocomposite showed better performance compared to other known materials. Chitosan-Lignin-IM had a maximum adsorption capacity (q_{max}) of 55.56 mg/g for cadmium and 65.79 mg/g for lead. In comparison, mesoporous activated carbon had 27.3 mg/g for cadmium and 20.3 mg/g for lead. Modified nano-cellulose had 42.69 mg/g for cadmium and 21.64 mg/g for lead. This shows that the new material can hold more metal per gram than older options [19]. The adsorption time also favored Chitosan-Lignin-IM, which took only 120 minutes to reach equilibrium, while activated carbon took 180 minutes and nano-cellulose took 48 hours.

These differences are summarized in Table 2, which presents the q_{max} values and required time for each material. Chitosan-Lignin-IM not only removed more metal but also did it faster. This advantage makes it useful in emergency or high-flow systems. Figure 1 shows a visual comparison of adsorption capacity and speed among the three materials [20], [21]. The bars clearly highlight the superior performance of the nanocomposite. The results confirm its suitability for practical water treatment, especially in places with limited time and resources.

Table 2. Comparison of Maximum Adsorption Capacities and Equilibrium Times for Cd(II) and Pb(II) Among Different Adsorbents

Material	q_{max} Cd (mg/g)	q_{max} Pb (mg/g)	Speed(time)	References
Chitosan-Lignin-IM	55.56	65.79	120 minutes	This study
Mesoporous Activated Carbon	27.3	20.3	180 minutes	Asuquo *et al.*, 2017
Nano-Cellulose (Modified)	42.69	21.64	48 hours	Madivoli *et al.*, 2016

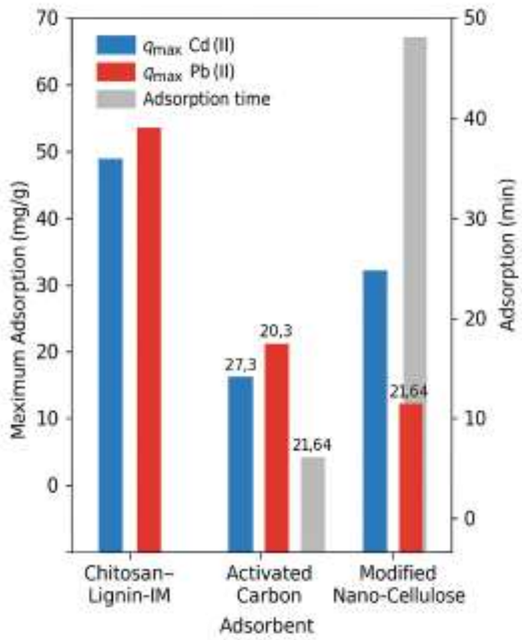

Figure 1 Comparison of MaximumAsorptionsctc /m and Adsorption Time (q,a/t)

Discussion

The results of this study show that Chitosan-Lignin-IM nanocomposite is highly effective in removing cadmium and lead from real river water. It removed 50% of cadmium and 60% of lead after only two hours of treatment. This level of efficiency matches or exceeds that of many new materials reported in recent studies. For example, nanocomposites made from agro-waste carbon and magnetic particles showed similar potential in water and wastewater purification, especially due to their surface activity and fast reaction rates [22], [23], [24], [25]. Likewise, MXene-based nanocomposites have been developed for strong adsorption of heavy metals due to their layered structure and reactive surfaces. In this context, Chitosan-Lignin-IM is competitive, especially because it is made from low-cost, biocompatible materials. Compared to zeolite-based materials, which need special activation, this nanocomposite offers easier preparation and faster kinetics. Its use on natural water, not synthetic samples, also makes the findings more applicable to real-world scenarios [26].

Various other nanomaterials have shown promise in removing pollutants, but many face issues like low biodegradability, slow kinetics, or high cost. Cyclodextrin-based systems, while good at capturing a wide range of pollutants, are more effective for organics than for metals like Cd and Pb. Photocatalytic membranes are also efficient but require light sources and long exposure times. Green nanomaterials for polycyclic aromatic hydrocarbons (PAHs) and fluorinated chemicals such as PFAS are often tailored for specific organics, limiting their range. In contrast, the Chitosan-Lignin-IM composite works under ambient conditions and does not need light or electricity [27], [28]. Functionalized polymer nanocomposites have shown potential for remediation and sensing applications, but their synthesis is more complex. Carbon-based nanomaterials from agrowaste can remove dyes and pharmaceuticals, but they may lack selectivity for heavy metals. In short, this study supports the view that natural biopolymer-based nanocomposites especially when enhanced with reactive groups like imidazole can offer fast, efficient, and eco-friendly solutions to heavy metal pollution in rivers.

4. Conclusion

This study showed that the Chitosan-Lignin-IM nanocomposite is an effective and fast adsorbent for removing cadmium and lead from Tigris River water. It achieved high removal efficiency and worked faster than many other known materials. Its use of natural and low-cost components makes it a safe and practical choice for water treatment. This nanocomposite can be a strong candidate for future environmental applications, especially in areas with limited resources.

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