

Application of a Cotinus-Derived Biosorbent for Copper Removal from Aqueous Media: Kinetic and Spectrophotometric Evaluation

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Abstract. Heavy metal contamination in aquatic systems remains one of the major environmental concerns associated with industrial development. Among various toxic pollutants, dissolved copper species are frequently encountered in industrial wastewater and may negatively affect both ecological systems and human health at elevated concentrations. In the present study, the adsorption performance of a plant-derived biosorbent prepared from saraghan material was systematically investigated using kinetic and spectrophotometric approaches. The biosorbent was obtained through drying and mechanical grinding without additional chemical modification. Adsorption experiments were performed under different contact times (5-30 min), pH conditions (3-7), and initial metal concentrations (10-50 mg/l). Spectrophotometric analysis demonstrated a significant decrease in absorbance intensity after treatment, indicating efficient metal uptake by the biosorbent surface. Equilibrium conditions were approached within approximately 30 minutes, while the removal efficiency ranged between 82% and 91% under optimal conditions. The adsorption process was strongly influenced by pH, and maximum performance was observed in near-neutral media. Kinetic calculations revealed good agreement with the pseudo-second-order model, suggesting that chemisorption mechanisms dominate the interaction process. The obtained findings indicate that cotinus-derived material can serve as a low-cost, environmentally friendly, and efficient biosorbent for heavy metal remediation in aqueous systems.

Keywords: biosorbent, heavy metals, adsorption kinetics, copper removal, spectrophotometric analysis, plant-based adsorbent, green chemistry

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Sulu mühitdən misin çıxarılması üçün Kotinus mənşəli biosorbentin tətbiqi: kinetik və spektrofotometrik qiymətləndirmə

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Xülasə. *Su sistemlərində ağır metal çirklənməsi sənaye tullantıları ilə əlaqədar ən aktual ekoloji problemlərdən biri hesab olunur. Xüsusilə həll olmuş mis birləşmələrinin yüksək konsentrasiyası ekosistemlər və canlı orqanizmlər üçün toksik təsirlərlə müşayiət olunur. Bu tədqiqatda sarağan bitkisindən əldə olunmuş bioadsorbentin adsorbsiya xüsusiyyətləri kinetik və spektrofotometrik üsullarla sistemli şəkildə araşdırılmışdır. Adsorbent qurudulma və mexaniki xırdalanma yolu ilə hazırlanmışdır. Təcrübələr müxtəlif zaman intervallarında (5–30 dəqiqə), pH mühitlərində (3–7) və ilkin qatılıqlarda (10–50 mq/l) aparılmışdır. Spektrofotometrik nəticələr adsorbsiya prosesindən sonra adsorbsiya intensivliyinin əhəmiyyətli dərəcədə azaldığını göstərmişdir. Optimal şəraitdə çıxarılma dərəcəsi 82–91% intervalında olmuşdur. Kinetik təhlillər adsorbsiya prosesinin psevdokinetik dərəcəli modelinə uyğun olduğunu göstərmişdir. Alınmış nəticələr sarağan mənşəli materialın ekoloji təhlükəsiz və perspektivli bioadsorbent olduğunu təsdiq edir.*

Açar sözlər: *bioadsorbent, ağır metallar, adsorbsiya kinetikasi, mis ionları, spektrofotometrik analiz, yaşıl kimya*

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Introduction

The contamination of water resources by heavy metals has become an increasingly significant environmental challenge worldwide. Rapid industrialization has resulted in the discharge of toxic metal-containing effluents originating from mining, electroplating, metallurgy, textile production, and chemical industries. Unlike many organic pollutants, heavy metals are non-biodegradable and may accumulate in biological systems over time, causing long-term ecological and toxicological consequences (Emenike, 2016).

Copper-containing contaminants are among the most frequently detected inorganic pollutants in industrial wastewater (Ivanova, 2025). Although copper is considered an essential trace element for biological metabolism, excessive concentrations may induce oxidative stress, protein denaturation, and cellular damage in living organisms. Consequently, the development of sustainable and efficient technologies for metal removal from aqueous environments remains an important research priority (Parus, 2018).

Conventional treatment methods, including ion exchange, membrane filtration, chemical precipitation, and electrochemical processes, often involve high operational costs and secondary waste generation. These limitations have encouraged the search for alternative adsorption materials derived from renewable natural sources (Freitas, 2019).

Plant-based biosorbents have emerged as promising alternatives due to their low cost, biodegradability, availability, and environmental compatibility (Ivanova, 2021). Such materials contain functional groups including hydroxyl, carbonyl, phenolic, and carboxyl moieties capable of interacting with dissolved metal species through coordination, ion exchange, and electrostatic interactions (Foroutan, 2018). Similar interaction behavior of oxygen and nitrogen-containing functional groups toward metal species has also been discussed in studies devoted to hydrazone-based organic ligand systems (Huseynova, 2025).

Several agricultural and plant-derived materials such as corncob, groundnut husk, cassava leaves, and lignocellulosic biomass have demonstrated considerable adsorption capacities toward heavy metal species (Ugwu, 2020). The adsorption efficiency of these materials depends on multiple parameters including pH, contact time, initial concentration, surface morphology, and functional group distribution (Paksamut, 2018).

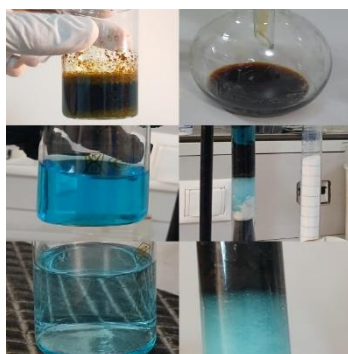
Adsorption kinetics provide valuable information regarding the mechanism controlling the interaction process. In many studies, the pseudo-second-order kinetic model has shown superior agreement with experimental data, indicating that chemical interactions may dominate the adsorption mechanism (Bahouch, 2025). Furthermore, adsorption systems involving plant-derived materials frequently exhibit Langmuir-type behavior associated with monolayer surface coverage (Sadok, 2019). The present work aims to evaluate the adsorption performance of a cotinus-derived powdered biosorbent for the removal of dissolved copper species from aqueous media and to investigate the process using kinetic and spectrophotometric methods.

Methods

Preparation of the Biosorbent. Cotinus plant material was collected and washed thoroughly with distilled water to remove surface impurities. The material was dried under ambient laboratory conditions and mechanically ground into fine powder form. No chemical activation or additional surface modification was applied before adsorption experiments.

Preparation of Model Solutions. Model metal-containing solutions were prepared using copper sulfate pentahydrate. The concentration range was adjusted between 10 and 50 mg/l. The pH values of the solutions were controlled using dilute hydrochloric acid and sodium hydroxide solutions.

Adsorption Procedure. Adsorption experiments were carried out under varying contact times (5, 10, 20, and 30 min) and pH conditions ranging from 3 to 7. A fixed amount of powdered biosorbent was added to the prepared solutions and continuously stirred during the adsorption process.



Picture 1
Different stages of the process

The removal efficiency was calculated according to the following equation:

$$R(\%) = \frac{C_0 - C}{C_0} \times 100$$

where C_0 represents the initial concentration and C corresponds to the equilibrium concentration of dissolved metal species.

Spectrophotometric Measurements

The concentration changes before and after adsorption were monitored using UV–Vis spectrophotometry. The decrease in absorbance intensity was used as evidence of successful adsorption onto the biosorbent surface.

Results

Effect of contact time. The adsorption process proceeded rapidly during the initial stage of interaction. A substantial fraction of dissolved metal species was removed within the first 10 minutes due to the availability of unoccupied active centers on the adsorbent surface. As adsorption progressed, the process gradually slowed because of saturation of available adsorption sites. Equilibrium conditions were approached after approximately 30 minutes. Under optimal conditions, the removal efficiency reached values between 82% and 91%.

The rapid adsorption kinetics observed in this study are consistent with previous reports describing plant-derived materials as efficient biosorbents for heavy metal remediation. **Influence of pH.** The pH of the medium significantly affected adsorption performance. Under acidic conditions (pH = 3), the removal efficiency remained comparatively low (54-63%). This phenomenon may be explained by competition between hydrogen ions and positively charged metal species for active adsorption sites.

An increase in pH resulted in enhanced adsorption efficiency, and the highest removal percentages were obtained in the pH range of 6-7. This behavior can be attributed to the deprotonation of oxygen-containing functional groups present on the biosorbent surface, which promotes stronger interactions with dissolved metal species.

Kinetic analysis. The adsorption kinetics were analyzed using the pseudo-second-order model:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$$

where q_t is the adsorption capacity at time t , q_e represents the equilibrium adsorption capacity, and k_2 corresponds to the pseudo-second-order rate constant.

The obtained kinetic data demonstrated good correlation with this model, suggesting that the adsorption mechanism is mainly governed by chemisorption processes involving surface functional groups (Begum, 2013).

Spectrophotometric Evaluation. UV–Vis spectrophotometric analysis showed a pronounced decrease in the characteristic absorbance intensity after adsorption treatment. The reduction in absorbance confirmed efficient uptake of dissolved contaminants by the cotinus-derived material. The adsorption capacity of plant-based materials strongly depends on their chemical composition and structural characteristics. Functional groups such as hydroxyl and carboxyl moieties play a significant role in metal binding through coordination interactions.

The use of naturally derived biosorbents offers important environmental and economic advantages over conventional treatment technologies (Devi, 2019). The cotinus-based material can be produced through simple processing techniques without requiring costly chemical modification or sophisticated instrumentation.

Furthermore, the utilization of plant-derived materials contributes to sustainable waste valorization and supports green chemistry principles in wastewater treatment applications. The low energy demand and environmentally compatible nature of biosorption processes increase their practical importance for future large-scale implementation.

Discussion and Conclusion

The present investigation demonstrated that cotinus-derived powder exhibits high adsorption efficiency toward dissolved copper-containing species in aqueous media. The adsorption process was significantly influenced by pH and contact time, with optimal performance observed under near-neutral conditions and approximately 30 minutes of interaction time. Kinetic studies indicated strong agreement with the pseudo-second-order model, suggesting that chemical interactions dominate the adsorption mechanism. Spectrophotometric analysis confirmed substantial reduction of dissolved contaminants after treatment.

The obtained results reveal that cotinus-derived biosorbent represents a promising low-cost and environmentally friendly material for heavy metal remediation. Its simple preparation procedure, efficient adsorption performance, and compatibility with sustainable environmental technologies make it a potential candidate for future wastewater purification applications.

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