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Akbarali RASULOV,
National University of Uzbekistan PhD student
E-mail: akbaralirasulov090@gmail.com
Elyor BERDIMURODOV,
National University of Uzbekistan professor
Khamdam AKBAROV,
National University of Uzbekistan professor
Davron KURONBOYEV,
National University of Uzbekistan PhD
Gulnora NAHANOVA,
National University of Uzbekistan Masters student

Based on the review of Associate Professor B. Bo‘rixonov from Qarshi State University.

FE_3O_4 ASOSIDAGI ADSORBENT YORDAMIDA PB^{2+} IONLARINI SUVLI ERITMALARDAN AJRATIB OLISH: SPEKTROSKOPIK TAVSIFLASH VA IZOTERMIK TAHLILI

Annotatsiya

Ushbu tadqiqotda suvli eritmalardan Pb^{2+} ionlarini samarali ajratib olish maqsadida magnetit asosidagi adsorbent sintez qilindi va uning adsorbsion xususiyatlari har tomonlama o‘rganildi. Strukturaviy va sirt funksional guruhlarini aniqlash uchun IQ tahlili o‘tkazildi. Natijalar Fe_3O_4 yadrosining saqlanib qolganligini hamda adsorbent yuzasida –OH, –NH, C=O va –COOH kabi funksional guruhlar mavjudligini tasdiqladi, bu esa og‘ir metall ionlari bilan o‘zaro ta’sir qilish uchun faol markazlar hosil bo‘lishini ko‘rsatadi. Pb^{2+} ionlarining adsorbsiyasi UV–Vis spektroskopiya yordamida tahlil qilindi. Vaqt o‘tishi bilan absorbans intensivligining muntazam kamayishi eritmadagi qo‘rg‘oshin ionlari konsentratsiyasining pasayganligini va adsorbsiya jarayonining samarali kechganligini ko‘rsatdi. Izoterma tahlillari Langmuir, Freundlich va Dubinin–Radushkevich modellari asosida amalga oshirildi. Natijalar adsorbsiya jarayonining asosan monomolekulyar qatlam hosil qilish mexanizmi bilan birga sirtning qisman geterogen tabiatini ham aks ettirishini ko‘rsatdi. Energetik tahlil esa ion–sirt o‘zaro ta’sirining muhim rol o‘ynashini tasdiqladi. Olingan natijalar magnetit asosidagi adsorbentning Pb^{2+} ionlarini suv muhitidan samarali ajratib olishda istiqbolli material ekanligini ko‘rsatadi.

Kalit so‘zlar: Fe_3O_4, Pb^{2+} ionlari, adsorbsiya, UV–Vis spektroskopiya, FTIR, izoterma modellari, Langmuir, Freundlich, Dubinin–Radushkevich, og‘ir metallarni tozalash.

УДАЛЕНИЕ ИОНОВ PB^{2+} ИЗ ВОДНЫХ РАСТВОРОВ АДСОРБЕНТОМ НА ОСНОВЕ FE_3O_4: СПЕКТРОСКОПИЧЕСКАЯ ХАРАКТЕРИСТИКА И ИЗОТЕРМИЧЕСКИЙ АНАЛИЗ

Аннотация

В данном исследовании был синтезирован адсорбент на основе магнетита с целью эффективного удаления ионов Pb^{2+} из водных растворов, и всесторонне изучены его адсорбционные свойства. Был проведен анализ методом ИК-Фурье спектроскопии (FTIR) для идентификации структурных и поверхностных функциональных групп. Результаты подтвердили сохранение ядра Fe_3O_4 и наличие на поверхности адсорбента функциональных групп, таких как –OH, –NH, C=O и C–O, что указывает на образование активных центров для взаимодействия с ионами тяжелых металлов. Адсорбция ионов Pb^{2+} контролировалась с помощью УФ-Вид спектроскопии. Регулярное уменьшение интенсивности поглощения со временем указывало на снижение концентрации ионов свинца в растворе и эффективное протекание процесса адсорбции. Изотермический анализ проводился на основе моделей Ленгмюра, Фрейндлиха и Дубинина-Радушкевича. Результаты показали, что процесс адсорбции в основном отражает механизм образования мономолекулярного слоя наряду с частично гетерогенной природой поверхности. Энергетический анализ подтвердил важную роль ионно-поверхностного взаимодействия.

Полученные результаты показывают, что адсорбент на основе магнетита является перспективным материалом для эффективного удаления ионов Pb^{2+} из водной среды.

Ключевые слова: Fe_3O_4, ионы Pb^{2+}, адсорбция, УФ-Вид спектроскопия, FTIR, изотермические модели, Ленгмюр, Фрейндлих, Дубинин-Радушкевич, очистка от тяжелых металлов.

REMOVAL OF PB^{2+} IONS FROM AQUEOUS SOLUTIONS USING FE_3O_4-BASED ADSORBENT: SPECTROSCOPIC CHARACTERIZATION AND ISOTHERM ANALYSIS

Annotation

In this study, a magnetite-based adsorbent was synthesized and its adsorption properties were comprehensively investigated for the purpose of effectively removing Pb^{2+} ions from aqueous solutions. FTIR analysis was performed to identify structural and surface functional groups. The results confirmed the preservation of the Fe_3O_4 core and the presence of functional groups such as –OH, –NH, C=O, and C–O on the adsorbent surface, indicating the formation of active sites for interaction with heavy metal ions. The adsorption of Pb^{2+} ions was monitored using UV–Vis spectroscopy. The regular decrease in absorbance intensity over time indicated a decrease in the concentration of lead ions in the solution and the effective progress of the adsorption process. Isotherm

analyses were performed based on the Langmuir, Freundlich, and Dubinin–Radushkevich models. The results showed that the adsorption process mainly reflects a monolayer coverage mechanism along with the partially heterogeneous nature of the surface. Energetic analysis confirmed the important role of ion-surface interaction.
The results obtained indicate that the magnetite-based adsorbent is a promising material for effectively removing Pb^{2+} ions from the aqueous environment.
Keywords: Fe_3O_4, Pb^{2+} ions, adsorption, UV–Vis spectroscopy, FTIR, isotherm models, Langmuir, Freundlich, Dubinin–Radushkevich, heavy metal removal

Introduction. One of the major water pollutants is heavy metals because this type of material is not biodegradable and accumulates in living organisms[1]. Thus, due to their toxicity and carcinogenic effects, heavy metal removal is a challenging task. Copper, lead, and chromium ions in industrial wastewater are toxic heavy metals of particular concern[2-4]. Currently, various approaches have been proposed for heavy metal removal from industrial wastewater. However, adsorption is preferred among them due to its advantages, including effectiveness, ease of operation, broad adaptability, high efficiency, and low cost[5]. Thus, various sorbents such as activated carbon, zeolites, biomass, and nanomaterials have been proposed[6]. Among the available adsorbents, nano-sized materials are promising and have been widely used for environmental treatment and remediation because nanomaterials exhibit high chemical activity and adsorption capacity[7, 8]. In this manner, magnetic nanoparticles are widely used in water treatment due to their ease of separation. Another type of nanoadsorbents are carbon nanostructures such as carbon nanotubes, graphene oxide, nanocarbons, and carbon nanocomposites[9].

On the other hand, nanocomposites exhibit improved or unusual properties, leading to the development of innovative applications. One of the important types of nanocomposites is magnetic carbon dots nanocomposites. Magnetic carbon dots nanocomposites show great application potential in various fields. In this way, magnetic carbon dots nanocomposites have been used to remove heavy metal ions[10-12]. Recently, Fe_3O_4/Carbon dots magnetic nanocomposite was introduced as a new synergistic nanozyme. In this study, the applicability of Fe_3O_4/Carbon dots magnetic nanocomposite as a nanoadsorbent for the removal of heavy metal cations, namely Pb(II) ions, was investigated. In this way, the mechanism of the adsorption process for cations was obtained by calculating kinetic parameters and the interaction between isotherm models.

Required Reagents. carbon dots, sodium hydroxide Fe_3O_4, $Pb(NO_3)_2$, HCl

Synthesis. Initially, carbon dots were dissolved in water, and a specific ratio of magnetic Fe_3O_4 nanoparticles was added. The mixture was stirred under heating for 4 hours. The resulting product was washed several times with water and ethanol to remove excess substances. The product was separated from the solution using a magnetic field and then dried.

Analysis of results. The composition of the best product obtained in pure form was examined using FTIR spectroscopy.

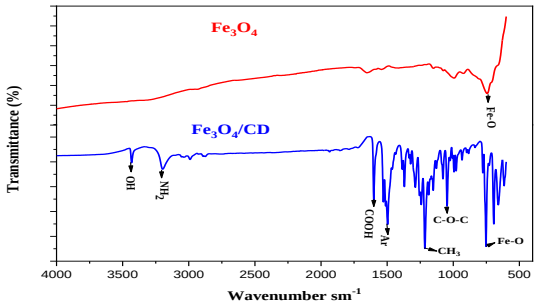

Figure 1. FTIR spectral analysis of Fe_3O_4 and Fe_3O_4/CD

The synthesized Fe_3O_4 and Fe_3O_4/CD nanocomposite samples were analyzed by FTIR in the range of 4000–500 cm^{-1} (Figure 1.). In the spectrum of pure Fe_3O_4, a strong peak observed in the 570–590 cm^{-1} region corresponds to the Fe–O stretching vibration, confirming the successful formation of the magnetite phase. In the Fe_3O_4/CD nanocomposite spectrum, additional characteristic peaks appeared. The broad peak around 3400 cm^{-1} corresponds to –OH/–NH groups and the peak around 1600 cm^{-1} corresponds to C=O or COO^- vibrations. Strong peaks in the 1000–1200 cm^{-1} range indicate C–O–C and C–O bonds. At the same time, the Fe–O signal in the 570–590 cm^{-1} region was also preserved in the composite. The results indicate that the surface of Fe_3O_4 was successfully modified with carbon functional groups while preserving the Fe_3O_4 core. These functional groups can increase the adsorption activity of the material.

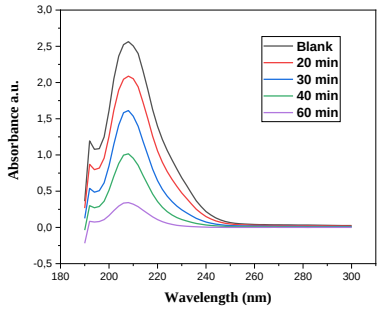

Figure 2. UV–Vis Analysis of Pb^{2+} Ion Adsorption

The UV–Vis spectra of the Pb^{2+} ion solution before adsorption and at different contact times were analyzed in the 190–300 nm range (Figure 2.). In the initial solution, a clear maximum absorption (λmax) is observed around ~205–210 nm. This peak is

specific to Pb^{2+} ions and represents the initial concentration in the solution. After adding the adsorbent, the overall intensity of the spectrum decreases regularly over time. In this case, the maximum wavelength remains almost unchanged, meaning that the peak position is maintained without shifting. This indicates that no new absorption centers were formed during the adsorption process, but rather that Pb^{2+} ions moved from the solution to the adsorbent surface. The preservation of the spectrum shape and only the decrease in intensity indicate that the process is mainly related to the decrease in concentration. According to Beer–Lambert's law, the decrease in absorbance value confirms the decrease in the amount of Pb^{2+} in the solution. The sharp decrease in absorption with increasing time indicates that the adsorption process is actively occurring and that the system is gradually approaching equilibrium. Overall, the UV–Vis results confirm that Pb^{2+} ions were effectively removed from the solution and that the adsorption process occurred gradually, depending on time.

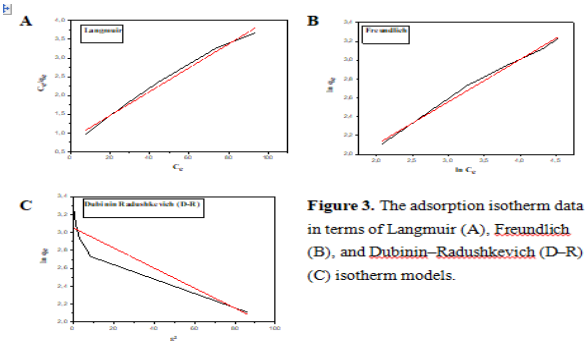

Figure 3. The adsorption isotherm data in terms of Langmuir (A), Freundlich (B), and Dubinin–Radushkevich (D–R) (C) isotherm models.

To evaluate the adsorption behavior of Pb^{2+} ions, the experimental results were analyzed based on the Langmuir, Freundlich, and Dubinin–Radushkevich (D–R) isotherm models (Figure 3.). The observation of linear dependencies in the obtained graphs indicates that the adsorption process occurs in accordance with the isothermal models. The results of the Langmuir model indicate that the adsorption process mainly occurs based on monolayer coverage, meaning that Pb^{2+} ions fill the active sites on the adsorbent surface. The Freundlich model, on the other hand, shows that the adsorbent surface is somewhat heterogeneous and that there are centers with different energies. The analysis of the Dubinin–Radushkevich model confirms that the ion-surface interaction is energetically significant in the process. Thus, the isotherm results show that the adsorption of Pb^{2+} ions occurs through a complex but orderly mechanism, and that the process involves monolayer coverage along with the energetic heterogeneity of the surface.

Conclusion. In this study, a magnetite-based adsorbent was synthesized, and its effectiveness in removing Pb^{2+} ions from aqueous solutions was comprehensively investigated. FTIR analysis results confirmed the successful formation of the Fe3O4 core and the presence of functional groups such as –OH, –NH, C=O, and C–O on the adsorbent surface. These functional groups were found to serve as active sites interacting with heavy metal ions.

UV–Vis spectroscopic results showed an effective reduction of Pb^{2+} ions from the solution over time, confirming that the adsorption process was consistent and efficient. Analyses based on isotherm models indicated that the adsorption process mainly occurs through a monolayer coverage mechanism, while also showing that the adsorbent surface has a certain degree of heterogeneous character. Energetic evaluation results confirm the important role of ion-surface interaction.

Overall, the results obtained indicate that the magnetite-based adsorbent is a promising material for effectively removing Pb^{2+} ions from the aqueous environment and justifies its potential application in the treatment of heavy metal-contaminated wastewater.

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