

Original Research Article

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Preparation of Iron-Based Beads for the Removal of Chromium from Artificial Wastewater

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ABSTRACT

Keywords

Iron oxide nanoparticles; Fe₃O₄; iron beads; chromium; Cr(III); wastewater; adsorption; magnetic adsorbent

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Chromium contamination of water is an important environmental concern because persistent heavy-metal pollution can adversely affect water quality and human health. The present study investigated the preparation of iron-based magnetic material by a chemical co-precipitation approach and its application for chromium removal from an artificial aqueous system. Fe₃O₄ nanoparticles were prepared from FeCl₃·6H₂O and FeCl₂·4H₂O in alkaline medium, followed by nitric-acid treatment and citrate stabilization. The resulting material was magnetically separated, washed, and freeze-dried, yielding 1.77 g of dried material. Chromium (III) chloride solution was used as a model wastewater, and treatment was evaluated under batch conditions using iron material at controlled pH and contact time. UV-Vis measurements were used for characterization of the synthesized iron material and chromium-containing solution. The synthesized material showed a dark brownish-black appearance and a reported UV-Vis feature in the 300–350 nm region. The experimental observations indicated chromium interaction with active sites on the iron material and demonstrated the potential of iron-based adsorbents for wastewater treatment. However, the present dataset does not provide sufficient quantitative residual-chromium concentrations to calculate removal percentage, adsorption capacity, adsorption kinetics, or isotherm parameters. Therefore, these parameters should be established in future work before definitive performance claims are made.

Introduction

Clean water is essential for human health, while rapid industrialization, population growth, and domestic and agricultural activities contribute to increasing water pollution. Heavy metals are of particular concern because

of their persistence in the environment and potential adverse effects even at relatively low concentrations.

The source document identifies heavy-metal pollution as a significant environmental problem and describes several treatment approaches, including photocatalytic

oxidation, chemical coagulation, electrochemical treatment, bioremediation, ion exchange, reverse osmosis, and adsorption. Among these approaches, nanomaterial-based adsorption is highlighted because of its potential for efficient pollutant removal.

Iron oxide materials are attractive adsorbents because of their small particle size, high surface area, and magnetic properties. Magnetic separation can facilitate recovery of the adsorbent after treatment and may reduce operational costs through reuse. The source document particularly emphasizes Fe₃O₄ (magnetite), together with other iron oxides such as γ -Fe₂O₃ and α -Fe₂O₃, as candidate materials for heavy-metal remediation.

Chemical co-precipitation is described as a widely applicable method for Fe₃O₄ nanoparticle synthesis. It involves the reaction of ferrous and ferric salts in alkaline aqueous medium.

The source material reports that particle formation is influenced by pH, ionic strength, concentration, temperature, and reaction conditions. Surface modification and composite formation have also been investigated to improve dispersion, stability, adsorption capacity, and recovery.

The present study therefore focuses on preparation of an iron-based magnetic adsorbent and its preliminary evaluation for chromium removal from an artificial wastewater system. The work combines material preparation, basic spectroscopic characterization, and batch treatment of chromium-containing solution.

The present study aims to synthesize and evaluate an iron-based adsorbent for the removal of chromium from wastewater, focusing on its preparation, characterization, and performance under controlled experimental conditions. The specific objectives are to synthesize iron oxide nanoparticles using the chemical co-precipitation method, characterize the synthesized iron-based material through spectrophotometric analysis, evaluate its chromium-removal efficiency in aqueous solutions, and investigate the possible mechanisms involved in chromium removal, including adsorption, reduction, and co-precipitation. Furthermore, the study seeks to assess the potential applicability of the synthesized material for wastewater treatment and to identify its suitability as an alternative adsorbent for reducing chromium contamination.

Materials and Methods

Synthesis of Fe₃O₄ nanoparticles

Fe₃O₄ nanoparticles were prepared by the basic co-precipitation method. FeCl₃·6H₂O (4.46 g; 16.6 mmol) and FeCl₂·4H₂O (1.6 g; 8.1 mmol) were dissolved in 80 mL deionized water at room temperature. The solution was degassed by bubbling argon for 5 min while stirring. Subsequently, 10 mL of 28–30% (w/w) ammonia was added dropwise, followed by stirring for 10 min at room temperature. The mixture was heated at 90 °C for 1 h.

The resulting magnetite-containing material was cooled and magnetically separated, then washed with deionized water until approximately pH 8 was reached.

The recovered Fe₃O₄ particles were treated with 2 M nitric acid for 5 min with stirring at room temperature. The particles were subsequently washed with deionized water and magnetically separated until the suspension reached approximately pH 2.5. Ten millilitres of 0.5 M aqueous sodium citrate was added to a 30 mL particle suspension, and the mixture was stirred for 1 h at room temperature to stabilize the particle surface. The citrate-stabilized particles were magnetically recovered, thoroughly washed with deionized water, and freeze-dried. The dried material weighed 1.77 g and was stored at 4 °C.

Preparation of artificial chromium wastewater

Chromium (III) chloride (CrCl₃) was dissolved in deionized water to prepare a stock solution, with the source document giving 1000 mg/L Cr³⁺ as an example. The stock solution was diluted to the desired experimental concentration, with a working range of 10–100 mg/L described in the protocol.

Batch treatment with iron material

A known mass of iron material (approximately 0.1–1.0 g) was added to 50 mL of chromium solution in a conical flask or batch reactor. The pH was adjusted to the required experimental value, with pH 5–7 indicated in the protocol, using HCl or NaOH. The mixture was incubated on an orbital shaker at 150–200 rpm or maintained under static conditions for 1–24 h. Following treatment, the iron material was separated from the aqueous phase by filtration or centrifugation.

Spectrophotometric analysis

UV-Vis spectrophotometric measurements were used for characterization. The source document reports absorbance/transmittance readings at wavelengths from 213 to 852 nm for the chromium-related spectrometric analysis. The available dataset contains very low absorbance values across the measured wavelengths; therefore, a validated analytical wavelength and calibration curve for quantitative chromium determination are not established in the supplied material.

Data analysis

For a publication-grade quantitative study, chromium removal should be calculated from initial and residual concentrations using $\text{removal (\%)} = [(C_0 - C_e)/C_0] \times 100$, where C_0 is the initial chromium concentration and C_e is the equilibrium/residual concentration. Adsorption capacity should be reported as $q = [(C_0 - C_e)V]/m$, where V is solution volume and m is adsorbent mass. These calculations were not applied to the present dataset because complete quantitative concentration data were not supplied.

Results and Discussion

Formation of iron oxide material

The co-precipitation procedure produced a dark brownish-black precipitate, which was interpreted in the source document as evidence of iron nanoparticle formation. Following purification, surface stabilization, magnetic separation, washing, and freeze-drying, the final dried material weighed 1.77 g

UV-Vis characterization

The source document reports a characteristic UV-Vis feature in the 300–350 nm region for the synthesized FeNPs. The chromium-related spectrometric dataset is reproduced below as supplied.

Chromium treatment

The batch-treatment experiment was designed to evaluate interaction between chromium (III) ions and the iron material. The source document reports that chromium

(III) ions bind to active sites on the iron material through electrostatic attraction or complexation and states that the iron beads demonstrated significant chromium removal under optimized conditions.

The preparation route used in this study is consistent with a chemical co-precipitation strategy for producing Fe_3O_4 -based magnetic material. The combination of ferrous and ferric salts in alkaline medium followed by thermal treatment provides a practical route to iron oxide formation. Surface stabilization with citrate was incorporated after acid treatment, with magnetic recovery used during washing and purification. The resulting material can therefore be handled using magnetic separation, an important practical advantage for wastewater-treatment applications.

The potential chromium-removal mechanism is primarily associated with interaction between chromium species and reactive surface sites. Adsorption may occur through electrostatic attraction or surface complexation. The source document also discusses reduction and co-precipitation as possible mechanisms, particularly when zero-valent iron or iron hydroxides participate in the treatment process. For Cr(VI)-containing wastewater, reduction to Cr(III) by reactive iron is a widely discussed remediation pathway; however, the experimental treatment reported here used chromium(III) chloride. Consequently, conversion of Cr(VI) to Cr(III) should not be presented as an experimental finding of this study.

Several experimental factors can influence chromium removal, including solution pH, initial chromium concentration, adsorbent dose, contact time, particle aggregation, and surface chemistry. The source literature reviewed in the document reports improved performance for a variety of functionalized iron oxide materials and highlights the importance of surface modification, regeneration, and magnetic recovery. These observations support further optimization of the present iron-based system.

In conclusion, Iron-based magnetic material was prepared by chemical co-precipitation of ferrous and ferric salts followed by acid treatment, citrate stabilization, magnetic separation, washing, and freeze-drying. The resulting material showed the expected dark brownish-black appearance and was evaluated as a potential adsorbent for chromium-containing artificial wastewater.

Fig.1 Iron (II) Chloride



Fig.2 Iron (III) Chloride



Fig.3 Treatment of chromium iii solution with iron bead

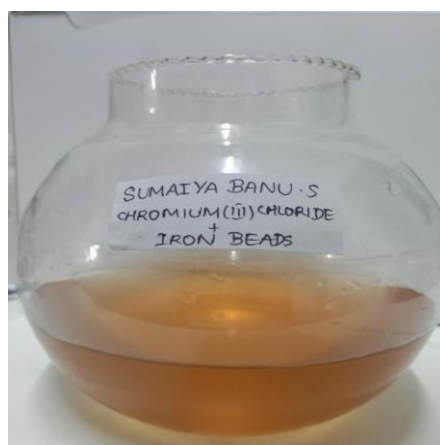


Fig.4 Preparation of iron beads



Fig.5 Synthesis of iron nanoparticles



Fig.6 Characterization of chromium using spectrometer

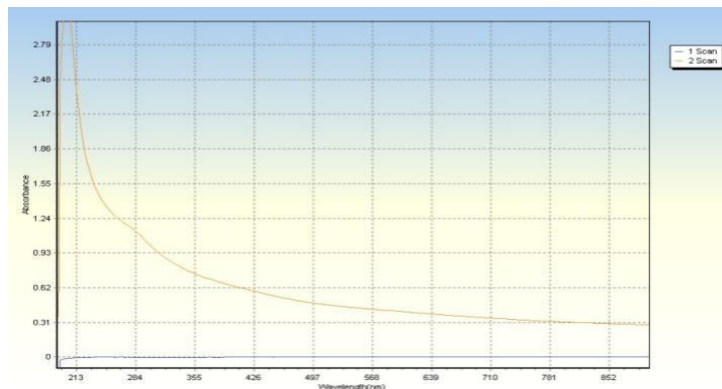


Fig.7 Adsorption of iron beads

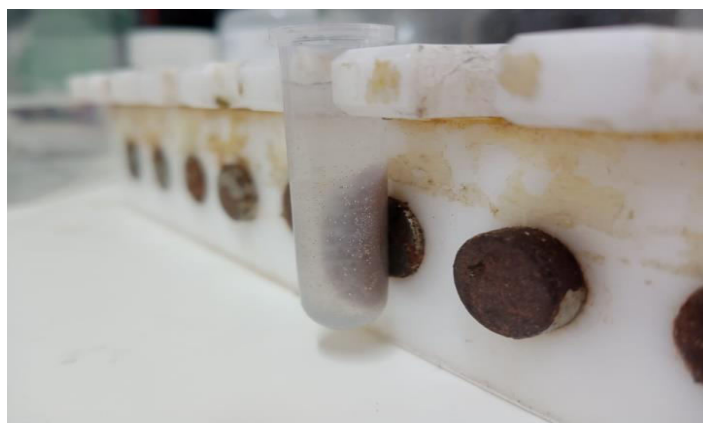


Table.1 UV-Vis readings supplied in the original document.

Wavelength (nm)	Absorbance	Transmittance
213	-0.0061	101.4103
284	-0.0014	100.3236
355	-0.0022	100.5061
426	0.0002	99.9526
497	0.0010	99.7692
568	0.0008	99.8133
639	0.0007	99.8382
710	0.0005	99.8757
781	0.0015	99.6579
852	0.0017	99.6185

The experimental design supports the feasibility of using magnetic iron-based materials for chromium treatment because they can be recovered magnetically and may interact with chromium through adsorption and related

surface processes. However, the current dataset is insufficient to establish a numerical removal efficiency or adsorption capacity. Future work should include validated chromium quantification, replicate

experiments, optimization of pH/adsorbent dose/contact time, adsorption kinetics and isotherms, regeneration studies, and appropriate statistical analysis.

Author Contributions

Sumaiya Banu S: Conceived the original idea and designed the model and wrote the manuscript. A. Sheela: Designed the model and the computational framework and analysed the data.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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