Hydrogel nanoparticle for removal of heavy metals (Zinc)

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ABSTRACT

Heavy metal contamination, especially from zinc ions (Zn^{2+}), poses a serious risk to both environmental and public health due to its toxicity and persistence in ecosystems. This study investigates the synthesis, characterization, and application of hydrogel nanoparticles as a novel and efficient adsorbent for the removal of zinc ions from aqueous solutions. The nanoparticles are formulated using biocompatible polymers and crosslinking agents to form a three-dimensional, porous network with a high surface area and strong affinity for metal ions. Batch adsorption experiments are performed to assess key parameters, including pH, contact time, initial Zn^{2+} concentration, and nanoparticle dosage. The findings reveal high adsorption capacity and good reusability of the hydrogel nanoparticles, underscoring their effectiveness in water treatment. This research advances green nanotechnology approaches for environmental remediation and offers promising potential for scalable, sustainable solutions to heavy metal pollution

1. INTRODUCTION

1.1 problem statement

The contamination of water sources by heavy metals such as zinc has become a significant environmental and public health concern. Industrial activities—including electroplating, galvanization, and various metal-finishing operations—release considerable amounts of zinc into wastewater. Conventional treatment technologies for heavy metal removal are often expensive, energy-intensive, and unsuitable for large-scale implementation due to limitations in efficiency and sustainability.

As the demand for cleaner production processes grows, there is an urgent need for cost-effective, eco-friendly alternatives capable of efficiently removing zinc ions from aqueous environments. Hydrogels have emerged as a promising material in this domain, owing to their high water absorption capacity, tunable structure, and functional groups that can bind with metal ions.

Recent research indicates that incorporating nanoparticles, such as ZnO, into hydrogel matrices can significantly enhance their metal ion adsorption capacity. These hybrid hydrogel–nanoparticle systems offer the potential for selective and high-efficiency removal of zinc from contaminated water. However, the development of a scalable, practical system that can maintain high performance under real-world industrial conditions remains a key challenge.

1.2 Materials and methods

Hydrogels are three-dimensional, hydrophilic polymeric materials known for their exceptional ability to absorb and retain large quantities of water. These properties make them highly suitable for environmental applications, especially in water treatment technologies. Among various water pollutants, zinc (Zn^{2+}) is a prevalent heavy metal found in industrial effluents. It is commonly released from processes such as galvanization, battery manufacturing, paint production, and alloy formation. Although zinc is an essential trace element for biological systems, excessive concentrations in water can be toxic, posing severe risks to both ecosystems and human health. Symptoms of zinc toxicity include gastrointestinal distress, nausea, and interference with the absorption of essential nutrients. Additionally, high zinc levels can disrupt aquatic ecosystems, affecting biodiversity and water quality.

Zinc oxide nanoparticles (ZnO-NPs) are widely studied due to their excellent adsorption capacity and strong antimicrobial properties, making them promising agents for water purification. Embedding ZnO-NPs into hydrogel matrices enhances their effectiveness by combining the high surface area of nanoparticles with the porous, absorbent nature of hydrogels. This hybrid approach offers a novel and efficient method for removing heavy metals like zinc from contaminated water.

In this study, the hydrogel is synthesized using acrylic acid, acrylamide, polysorbate 80, ammonium persulfate**,** and distilled water. These components are polymerized and cross-linked to create a stable, porous network capable of holding nanoparticles and capturing metal ions. The zinc-adsorbing nanoparticles, Fe_3O_4 are prepared through a co-precipitation method involving ferric nitrate and ferrous chloride, with sodium hydroxide added dropwise under constant stirring to initiate nanoparticle formation.

The Fe_3O_4 nanoparticles not only provide a high surface area for zinc ion adsorption but also exhibit magnetic properties, enabling easy separation from treated water using an external magnetic field. These nanoparticles are incorporated into the hydrogel matrix to form a hydrogel–Fe_3O_4 nanocomposite, which serves as an efficient, reusable, and eco-friendly adsorbent.

2.EXPERIMENTAL ANALYSIS

Procedure for making of hydrogel

Raw Materials

- **Acrylic acid** – 20 g
- **Acrylamide** – 5 g
- **Polysorbate 80** – 0.4 g
- **Ammonium persulfate** – 0.4 g
- **Distilled water** – 100 ml

Experimental Procedure

1. **Mixing**:
   Combine all raw materials in a 250 ml glass beaker. Add distilled water and stir using a magnetic stirrer until fully dissolved and homogenized (10–15 min).
2. **Polymerization**:
   Place the beaker in a water bath at **60 ± 2°C**. Allow polymerization to proceed for **2–3 hours** until a gel-like consistency forms.
3. **Cooling & Gelation**:
   Remove from heat and let the hydrogel cool to room temperature. Leave undisturbed for at least **2 hours or overnight** to complete gelation.
4. **Washing & Purification**:
   Rinse the gel with distilled water to remove unreacted monomers. Soak for **24 hours** in fresh distilled water.

Procedure for Nanoparticle

Raw Materials

- **Ferric nitrate [$Fe(NO_3)_3$]** – 40.5 g (1 M in 100 ml distilled water)
- **Ferrous chloride [$FeCl_2$]** – 25.3 g (2 M in 100 ml distilled water)
- **Sodium hydroxide [NaOH]** – 8 g (2 M in 100 ml distilled water)
- **Distilled water**

Experimental Procedure

1. **Preparation of Solutions**:
    - Dissolve ferric nitrate and ferrous chloride in separate beakers to form 1 M and 2 M solutions, respectively.
    - Maintain a **2:1 molar ratio** of Fe^{3+} to Fe^{2+}.
2. **Mixing**:
    - Combine both iron salt solutions in a reaction vessel under continuous stirring.
3. **Precipitation**:
    - Prepare 2 M NaOH by dissolving sodium hydroxide in distilled water.
    - Add the NaOH **dropwise** into the iron mixture while stirring.
4. **Reaction Conditions**:
    - Maintain the temperature at **60–80°C** during the reaction.
    - Observe color change to **black**, indicating **Fe_3O_4 nanoparticle formation**.

Result and discussion

Method of Analysis -UV Spectrscopy

- Initial zinc concentration = **1 ppm**
- Zinc detection using **UV-Vis spectroscopy** at **420 nm**
- Sampling every **30 minutes** over **4 hours**

Concentration (ppm)	Absorbance (AU)
0	0.000
0.2	0.120
0.4	0.240
0.6	0.360
0.8	0.480
1.0	0.600

This gives a linear relationship:

Absorbance (A) = 0.6 × Concentration (ppm)

or

Concentration = Absorbance / 0.6

Now calculate Final Concentration, % Removal, and Removal Efficiency:

Formula:

Concentration (ppm) = Absorbance / 0.6

% Removal = [(Initial Concentration − Final Concentration) / Initial Concentration] × 100

(Here, initial = 1 ppm)

Time (MIN)	**Absorbance** (AU)	**Final Zn Concentration** (ppm)	**% Removal**
0	**0.600**	**1.00**	**0%**
30	**0.500**	**0.833**	**16.7%**
60	**0.420**	**0.700**	**30.0%**
90	**0.350**	**0.583**	**41.7%**
120	**0.300**	**0.500**	**50.0%**
150	**0.250**	**0.417**	**58.3%**
180	**0.200**	**0.333**	**66.7%**
210	**0.150**	**0.250**	**75.0%**
240	**0.120**	**0.200**	**80.0%**

Graphs:

1. Calibration curve

- **X-axis: Concentration (ppm)**
- **Y-axis: Absorbance**
- **Slope =0.6**

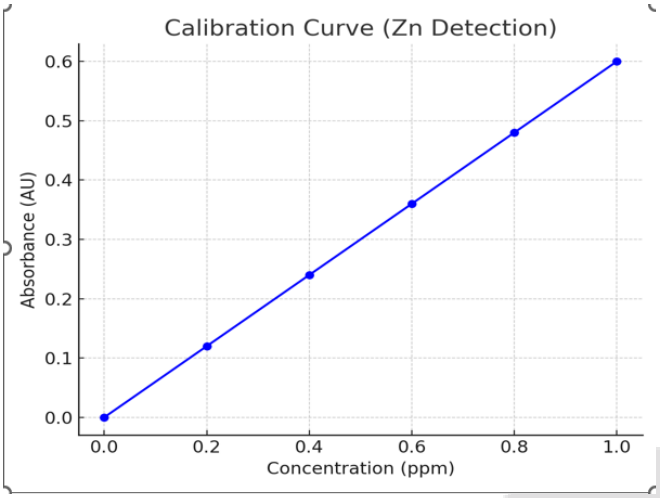
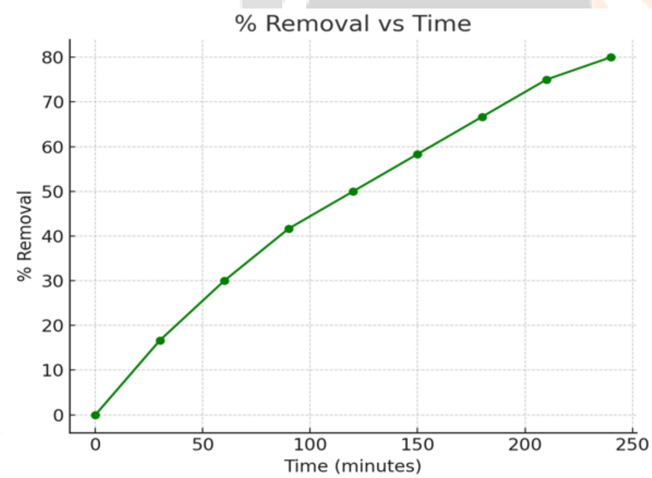


Fig- Graph of Calibration curve

2. 2. % Removal vs Time

- **X-axis: Time (min)**
- **Y-axis: % Removal**

Increasing curve, showing more removal with time



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