

Cadmium removal from industrial wastewater *via* magnetite nanoparticles

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Abstract

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Magnetic particles are widely used in many biological and medical fields, such as enzyme and protein immobilization, genes, magnetic resonance imaging (MRI), diagnostics, RNA and DNA purification, and magnetic cell separation and purification. This study investigated the role of magnetite nanoparticles in the extraction of arsenic from groundwater and industrial sources. The major goals of the work are the development of a sustainable water treatment system and the adsorption of Cd onto magnetic nanoparticles that are free of surfactants and soluble in water. A simple precipitation method was attempted to produce magnetite (Fe_3O_4) nanoparticles with a regulated size without the need for a high-temperature calcination phase. Magnetite nanoparticles were synthesized by sol-gel method and characterized by SEM images. Magnetite nanoparticles with a diameter of 15 nm have been applied to enforce the sedimentation of the solid waste to absorb the arsenic ions in water in the area of water purification. The cadmium removal capacity was evaluated for the synthesized nanoparticle.

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Introduction

The production of magnetite (Fe_3O_4) nanoparticles has long piqued interest due to their numerous technical uses, particularly as ferrofluids. According to (Enzel et al., 1999), a ferrofluid is a colloidal suspension of appropriately coated magnetite particles in a liquid medium that possesses unique features because of the combined influences of magnetic and fluid mechanics. Its numerous uses include position sensing, oscillation damping, rotary shaft seals, high speed CD drive protection, and audio speaker performance enhancement (Raj and Moskowitz, 1990). Ferrofluids have promising potential uses in biomedicine. Super-paramagnetic nanoparticles have enormous promise for achieving

these desired characteristics. To create Fe_3O_4 particles in the nanoscale size range, several techniques have been devised (Enzel et al., 1999). However, the synthesis process has a significant impact on the magnetic characteristics of magnetite-based nanoparticles or films (Margulies et al., 1996; Sena et al., 1997; Voogt et al., 1998). Here, we present a new and easy chemical method for creating magnetite (Fe_3O_4) nanoparticles in the 5–100 nm size range without the need for high-temperature calcination. Research on the size effect of these nanoparticles aids in determining the ideal size of Fe_3O_4 particles for ferrofluid production and other uses. Any minuscule particle with at least one dimension less than 100 nm is referred to as a nanoparticle, nanopowder, nanocluster,

or nanocrystal. Because nanoparticles have so many potentials uses in biological, optical, and electronic fields, scientists are currently conducting extensive study in this fields. Because they serve as an efficient link between atomic or molecular structures and bulk materials, nanoparticles are of tremendous scientific interest. Iron oxide particles with dimensions ranging from 1 to 100 nanometers are known as iron oxide nanoparticles. Magnetite (Fe_3O_4) and its oxidized counterpart maghemite ($\gamma\text{-Fe}_2\text{O}_3$) are the two primary forms. Because of their superparamagnetic characteristics and prospective uses in a wide range of sectors, they have garnered a lot of attention (while Co and Ni are also highly magnetic compounds, they are poisonous and easily oxidized).

Several methods were then used to characterize the magnetite particles that were so created. The X-ray diffractometer (XRD) was employed to identify the structural phase. Coherently diffracting domain size (dxrd) was calculated from the width of the XRD peak under the Scherrer approximation (which assumes the small crystallite size to be the cause of line broadening) after correcting for instrumental broadening. Because they serve as an efficient link between atomic or molecular structures and bulk materials, nanoparticles are of tremendous scientific interest. Iron oxide particles with dimensions ranging from 1 to 100 nanometers are known as iron oxide nanoparticles. Magnetite (Fe_3O_4) and its oxidized counterpart maghemite ($\gamma\text{-Fe}_2\text{O}_3$) are the two primary forms. Because of their superparamagnetic characteristics and prospective uses in a wide range of sectors, they have garnered a lot of attention (while Co and Ni are also highly magnetic compounds, they are poisonous and easily oxidized). Several methods were then used to characterize the magnetite particles that were so created. The X-ray diffractometer (XRD) was employed to identify the structural phase.. Over 40% of the world's population, or more than 2 billion people, lack access to enough clean water due to the paucity of water resources, according to data from the World Health Organization (WHO). Millions of people's health around the world is being impacted by the rising concentrations of several contaminants in groundwater and wastewater as a result of industrial and urban activity. Therefore, wastewater treatment and groundwater remediation are crucial. Cadmium is a heavy metal that should be eliminated from water using specific adsorbing methods. Cadmium molecules have been extracted from water using magnetite nanoparticles. The size of the nanoparticle

also plays a role in adsorbing capacity of the particle. The size of the particle was evaluated by SEM. The objective of this study is to synthesize magnetite nanoparticles with controlled size and to investigate their cadmium (Cd) removal efficacy.

Materials and methods

Chemicals and reagents

Chemicals used in this study included Na As, FeCl_2 , FeCl_3 , ammonia solution, and NaOH, most of which were received untreated from Merck Co. The solutions were prepared using deaerated deionized water containing 99.9% nitrogen for two hours. In the lab, magnetite nanoparticles were created by expanding the sol-gel method that was already in place.

Synthesis of Magnetite Nanoparticles

First, nitrogen gas will bubble 200 ml-1 of deoxygenated, filtered water (with a resistivity of $18\text{M}\Omega$) for 30 minutes. The aforesaid mixture will next be mechanically stirred to dissolve 5.2 g of FeCl_3 and 2 g of FeCl_2 . The aforesaid mixture will be vigorously stirred as 1.5 mol l-1 NH_4OH solution is added dropwise while being protected by nitrogen gas. A black precipitate will occur following the formation of an initial brown one.

Characterization of Magnetite Nanoparticles

An external magnetic field will be used to separate the black precipitate that formed when the stirrer was switched off and the magnetite gradually settled until the pH hit 8. The supernatant will then be decanted and described for additional structural investigation.

Cadmium removal using nanoparticles

The ability of NPs to adsorb was investigated using a cadmium-contaminated water sample. The adsorption process involved using 0.25 l (1.5 g of nanoparticles were stirred in 1 l of the cadmium solution) for a duration of 1 to 60 minutes, after which the nanoparticles were collected using an external magnet. Atomic absorption spectroscopy (AAS) was used to measure the amount of cadmium that remained in the solution.

SEM analysis

SEM was used to assess the size of the nanoparticles, and slides were prepared with the nanoparticles and SEM images were taken. Hitachi SEM Model S-3400N
Key Features: Detectors: Secondary Electron; Semiconductor BSE (Quad type); Resolution up to 3nm @ 30kV HV mode; Magnification: 5x to 300,000x; Vacuum System: TMP & Rotary: 1.5×10^{-3} Pa

Collection of cadmium contaminant water samples

From Neyveli Lignite Corporation in Neyveli, Tamil Nadu, a water sample was taken. The pharma analytical laboratory in Pondicherry used atomic absorption spectrophotometry to assess the cadmium content of the obtained samples (1 l). Experiments involving the elimination of cadmium use it.

Results

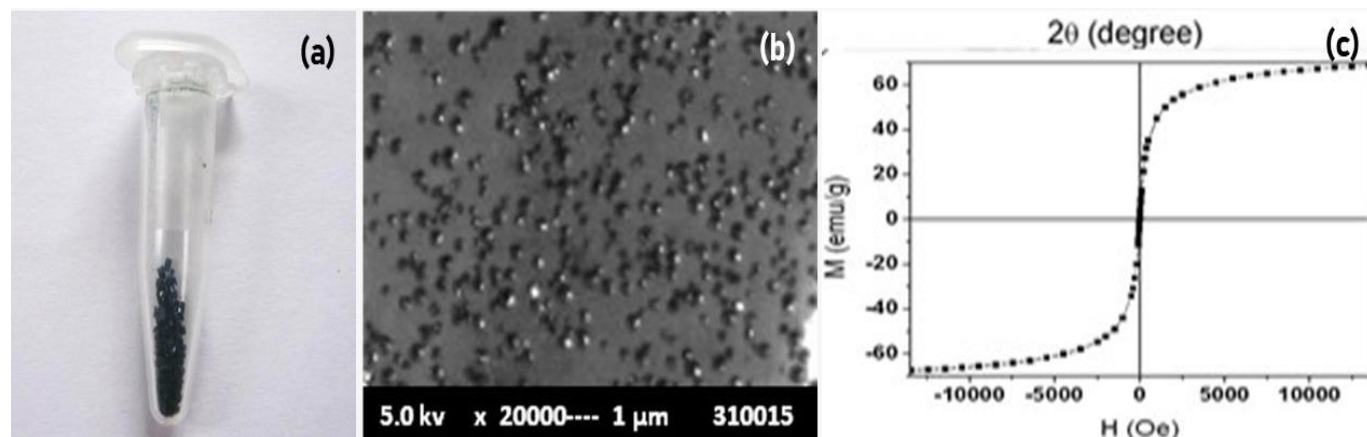


Fig. 1: (a) Fe₃O₄ nanoparticles (b) Effect of particle size on magnetic transition temperature and saturation magnetization of Fe₃O₄ nanoparticles, (c) Magnetic curve of synthesized Fe₃O₄ nanoparticles

Table 1. Time and Concentration of Cadmium removal

Time (min)	Cd concentration (μM)
0	52
5	44
10	41
30	32
60	11

Characterization

The nanoparticles are spherical in shape and range in size from 10 to 15 nm, according to the SEM pictures. The average size of the particles was 10.7 nm. The saturation magnetization was $2.5 \mu\text{B fu}^{-1}$, and the melting temperature was $533 \text{ }^\circ\text{C}$.

Magnetization curve of magnetite nanoparticles

The magnetite nanoparticles' field dependence of magnetization demonstrated that the samples were superparamagnetic at normal temperature.

Cadmium removal

The removal of cadmium from contaminated water was done with increasing time interval from 0 min to 60 min. As the time increases the cadmium concentration in the water decreases which is the evidence of magnetite nanoparticles to remove the Cd from contaminated water.

Discussion

Applications for magnetic nanoparticles in biology and the environment are beneficial. The sedimentation of solid waste in water and the adsorption of cadmium ions were facilitated by the combination of magnetic nanoparticles and a conventional method of water treatment. Following treatment, the nanoparticles can be separated from the sample solution thanks to their magnetic activity. According to the study, ultrasmall NPs are a promising substance for effectively removing As from water. It is possible to create a composite with

a bigger size that nevertheless maintains its magnetic properties and elimination of As with rapid kinetics. Their great compliance with existing water treatment technology makes them a very attractive alternative to extracting As from contaminated drinking water or groundwater.

Conclusions

The average size of the spherical nanoparticles was 10 nm. One promising strategy for eliminating cadmium contamination from water was the sol-gel synthesis of magnetite nanoparticles.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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