



Simple, Rapid and Efficient Water Purification by Chitosan Coated Magnetite Nanoparticles

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Abstract

Chitosan coated magnetite nanoparticles were prepared and used as adsorbent, chelating agent or bactericidal agent to remove organic contaminants, heavy metals, and bacteria from water. The method is simple and rapid. The obtained results are promise, where the prepared particles able to remove more than 90% and 60% from organic and inorganic contaminants respectively. Also chitosan coated magnetite nanoparticles inhibited the bacterial growth at concentration 2% w/v.

Keywords: Chitosan; Heavy metals removing; Magnetic nanoparticles; Organic contaminants.

1. INTRODUCTION

Recent human life causes continuous accumulation of organic, inorganic, and biological contaminants in the environment. Purification of water has attracted the greater interest mainly due to the restricted quantities of water that can be safely used directly and the high cost of purification installations (Lalov *et al.* 2000). Many efforts have been reported in the literatures to clean wastewater either by chemical or biological methods (Rao and Viraraghavan, 2002; Santiago *et al.* 2005; Renault *et al.* 2009).

Chitosan is a polysaccharide comprising copolymers of glucosamine that can be prepared by partial deacetylation of chitin (Yu *et al.* 2013). Chitosan is known as an ideal natural support for enzyme immobilization due to its hydrophilicity, biocompatibility, biodegradability, non-toxicity and good adsorption properties (Boddu *et al.* 2003). In water treatment, chitosan have been used as an adsorbent to remove organic pollutants, heavy metals, and oils. Also chitosan has showed an antimicrobial activity (Qi *et al.* 2004; Nomanbhay and Palanisamy, 2005; Rangel-Mendez *et al.* 2009; Wan Ngahet *et al.* 2011; Barrosa *et al.* 2014; Zhou *et al.* 2014). Chitosan coated magnetite nanoparticles (CMNP) is a type of

nanoparticles that contain a core of a magnetic material, usually a mixture of magnetite (Fe_3O_4) and maghemite ($\gamma\text{-Fe}_2\text{O}_3$) coated with thin chitosan layer (Zeinali *et al.* 2012). The binding of chitosan onto Fe_3O_4 nanoparticles affords novel magnetic nano-adsorbent for the efficient water purification. Where the nano-scale particles allow the highest surface area for adsorption and the magnetic core allows the easy separation of contaminated particles by applying outer magnetic field. This study introduces the using of CMNP as an efficient technique in water purification from different chemical and biological pollutants.

2. MATERIALS & METHODS

2.1 Materials

Chitosan (low molecular weight) was purchased from Sigma–Aldrich (USA). FeCl_3 , FeCl_2 copper sulphate, lead acetate and crystal violet were purchased from Merck (Germany). Muller–Hinton agar was purchased from Difco (England). Crude petroleum oil and wastewater were obtained from local sources.

2.2 Preparation of Fe_3O_4 nanoparticles

The magnetite (Fe_3O_4) nanoparticles were prepared by a chemical co-precipitation of Fe (III) and

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Fe (II) ions. An equal volumes of (0.2 mol/L) FeCl_2 and (0.3 mol/L) of FeCl_3 aqueous solution were mixed under the presence of N_2 gas. The solution was heated up to 60°C , then NH_4OH (25% w/v) was dropped into the mixture with vigorous stirring. The black precipitate that formed was collected by magnetic separation, washed several times with deionized water and finally dried at room temperature.

2.3 Preparation of chitosan coated Fe_3O_4 nanoparticles

0.5 g Chitosan solution was dissolved in 50 ml 2% (v/v) acetic acid. 10 ml of this solution was used to suspend 30 mg of MNPs. The mixture was vigorously stirred for 30 minutes then 2.5 ml NaOH (1N) was added drop wisely to precipitate the coated MNPs. The particles were magnetically separated, washed several times by deionized water and dried at room temperature under nitrogen stream.

2.4 Characterization

Structure and size of crystals were determined by XRD on a Rigaku MINIFLEX II X-ray diffractometer using Cu K α radiation ($\lambda = 1.540562$). TEM observation was performed on a microscope (JEOL JAM-2100-HR-EM).

2.5 Removing of oil spills

0.1 g crude petroleum oil was mixed with 10 ml water and different weight of CMNP (0.1–1 g). The mixture was vigorously stirred for 60 minutes and allowed to stand for another few minutes. The contaminated CMNP was separated magnetically while the oil residue was extracted by hexane. The amount of remaining oil was determined by weighing the residual oil after hexane evaporation.

2.6 Removing of dyes

Dyes removal experiments were carried out in a 250 mL flask while using crystal violet and methyl orange. 50 mL of solution pH 4, CMNP (0.1–1 g), and pollutant concentration (0.05 g), were agitating at 100 rpm for 60 min. Aliquots were carefully withdrawn from the solution at various time intervals to determine the concentration of remaining dyes by measuring the absorbance at 590 nm for crystal violet, and 480 nm for methyl orange.

2.7 Removing of heavy metals

50 mL of an aqueous solution of known metal concentration (0.1 mmol/L) and (0.1–1 g) of

CMNP were incubated at room temperature under constant agitation rate 100 rpm and pH 4. Every 20 minutes, a small sample was taken from the flask to determine the metal concentration by flame Atomic Absorption Spectrophotometry (Buck scientific VGP 210). The amount of metal removed was calculated as per cent of initial concentration.

2.8 Inhibition of bacterial growth

Five test tubes containing (0, 0.1, 0.2, 0.5, 1 g) CMNP and 10 ml of sterilized distilled water were prepared. To each tube 0.1 ml of the wastewater was added then the mixture was stirred for 1 h at constant rate. From each of those tubes one mL was inoculated on Muller–Hinton agar plate and examined for signs of growth by incubation at 37°C for 24 hrs. The bacterial concentration was determined as CFU and taken as an indicator for bacterial growth inhibition.

3. RESULT & DISCUSSION

3.1 Synthesis and characterization of chitosan coated magnetite nanoparticles

From X-ray diffraction analysis (fig. 1) and TEM Imaging (fig. 2), it is clear that we obtained Fe_3O_4 (magnetite) as a single mineral phase in nano average size 10–20 nm.

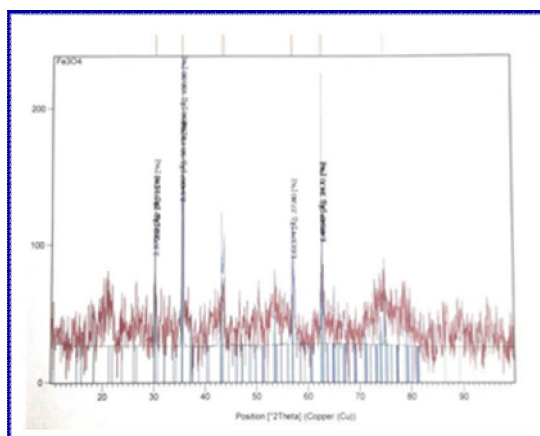


Fig. 1: X-ray diffraction analysis of the prepared magnetite

3.2 Removing of organic contaminants and heavy metals

The presence of amino groups in chitosan structure leads to the binding of metal cations by formation of complexes or chelation. The protonation of these groups in acidic media causes high affinity

for anionic compounds (metal anions, organic compounds, dyes) [7]. The acidic pH has been reported as the best condition for using chitosan as adsorbent [7-13]. So pH 4 was selected as an optimum pH for all experiments.

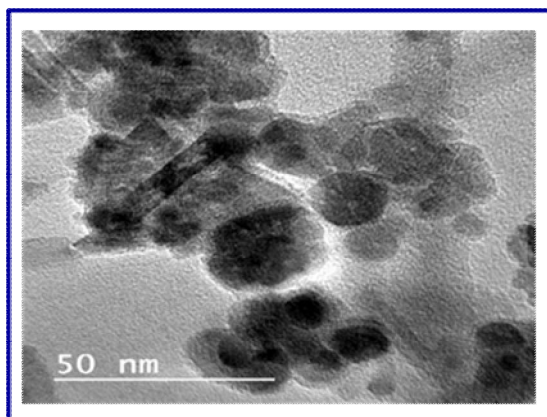


Fig. 2: TEM images of magnetic nanoparticles

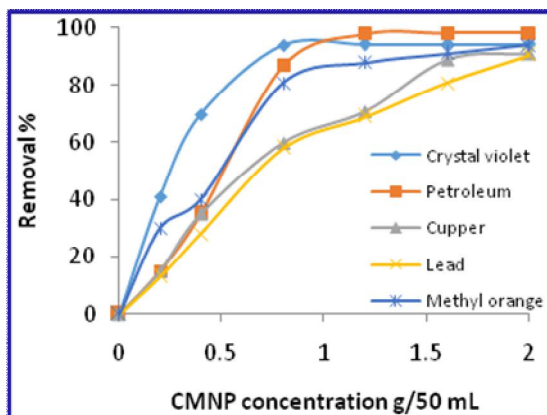


Fig. 3: The relation between CMNP concentration and the removal % of different contaminants

3.2.1 Effect of CMNP concentration

As shown in fig. 3, the adsorption capacities of the different contaminants considerably increased with CMNP concentration. The highest affinity was found with petroleum, where 1g of CMNP removed about 98% from it, while the lowest capacity was recorded by heavy metals that showed semi equal removing percentage.

3.2.2 Contact time

The adsorption capacity showed a significant increase during the first 20 minutes and then gradual increase in% sorption by increasing shaking time till

40 minutes (fig 4). On the basis of this observation, a 40 minutes shaking time were found suitable for the maximum sorption. Figure shows the relation between the contact time and the amount of contaminants removed by CMNP.

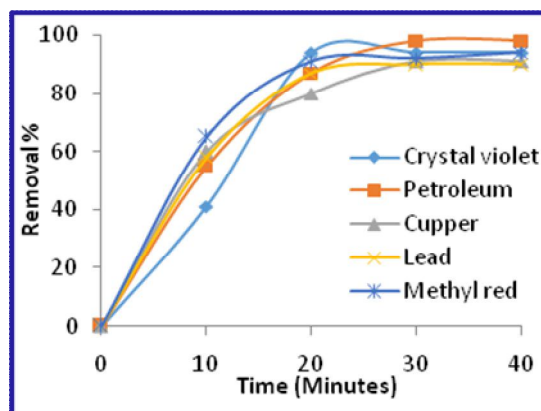


Fig. 4: The relation between contact time and the removal % of different contaminants

3.3 Inhibition of bacterial growth

Although the exact mechanism of the antimicrobial action of chitosan is still unknown, different mechanisms have been proposed. The positively charged amino groups in chitosan bind to the negatively charged bacterial surface to cause agglutination, alteration of cell permeability and leaking of intracellular constituents. In our experiment, CMNP have partially inhibited the bacterial growth at concentration 0.1 g/mL, the complete growth inhibition has occurred by concentration 0.5 g/10 mL.

4. CONCLUSION

Chitosan coated magnetite nanoparticles were synthesized and successfully used to remove different contaminants from water. The high capacity of the synthesized particles, the process simplicity and material availability make CMNP an excellent tool for water purification. We recommend the investigation of using CMNP in treatment of wastewater from different source such as industrial and agriculture sources.

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