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Wastewater Treatment using Magnetic Nanoparticles and Nanocomposites

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ABSTRACT

The application of magnetic nano-photocatalysts in clean water technologies, has been widely studied due to their improved chemical and physical properties. Due to the incorporation of magnetic materials into the nano-photocatalysts, the separation of the resultant nanocomposite can be facilitated via an applied external magnetic field, leading to more economic and also more ecologically friendly water refinement procedure. This paper presents a short review of magnetic nanomaterials in the purification of contaminated water/wastewater.

Keywords: Magnetic, Nanomaterial, Wastewater treatment, Nanocomposite, Water treatment

Introduction

The population growth around the world, despite the limited clean water resources, increases the concern about proving safe and clean water to meet human and animal needs. More than 10 percent of people in the world do not have access to proper drinking water [1]. In developing countries, about 80% of deseaes are related to deficient water and hygiene conditions [2].

In recent years, magnetic nanomaterials (MNPs) have been applied for elimination of water contaminants, for example pesticides, aromatics, dyes, and also heavy metals [10]. There are various techniques available for water purification such as precipitation, adsorption, ion exchange, solvent extraction, reverse osmosis, evaporation, membrane separation, and photocatalysis. The progress of nanotechnology and nanoscience reveals the capability of these methods in discarding harmful materials from the water. The fabrication and development of nanomaterials with the size of 1–100 nm illustrating exceptional properties compared to the bulk materials, gives rise to the various enhancements in many divisions such as electronics, environmental remediation, health, and manufacturing.

Magnetic MNPs have very fascinating properties such as small size and therefore large surface to volume ratio, significant biocompatibility, magnetic separation, specificity, surface chemistry and reusability. Magnetic NPs, specially nanoscale zero-valent iron, magnetite (g-Fe_2O_3) and maghemite (Fe_3O_4), have a lot of applications in biology, medicine, and water treatment [3]. The magnetic iron oxide nanoparticles are categorized in three different groups: paramagnetic, ferromagnetic and superparamagnetic [4]. In paramagnetic class, the magnetic dipoles are randomly oriented at usual temperatures because of unpaired electrons, that leads to a small positive magnetic susceptibility (weak interaction) in an external magnetic field. Superparamagnetic materials show a higher magnetic susceptibility than paramagnets because the magnetic dipole moments of the whole nanoparticle line up in the direction of the applied external magnetic field. Finally, in ferromagnetic materials all the dipole moments in one domain are aligned in the same direction even in the absence of an applied magnetic field, however under the effect of an enough strong magnetic field, the number of the domain structures can significantly decrease. The magnetic nanomaterials with functionalized surface chemistry have been widely used in water treatment. In this paper, application of magnetic materials for various processes of drinking water treatment and wastewater treatment has been described.

Synthesis of Magnetic Nanoparticles

Recently different chemical synthesis methods have been evolved to prepare monodisperse

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superparamagnetic NPs with customized configuration, dimension, surface chemistry and accumulation state [5].

Co-precipitation

Co-precipitation is a simple and practical method for iron oxide magnetic nanoparticles usually at room temperature or higher. This method leads to preparation of significant quantities of NPs in a single batch, although it is accompanied by a large size distribution [6, 7].

Microemulsion

Microemulsion is a system consisting of three components of oil, water and surfactant that makes a thermodynamically isotropic and stable solution. Based on the concentrations of various constituents, microemulsions can form water in oil (w/o) [8] or oil in water (o/w) microemulsion [9]. The surfactants used in this method can be cationic, anionic, or non-ionic. The significant advantage of this method is that it can lead to the fabrication of nanoparticles with a narrow size distribution. The dimension of the particles can be customized with adjusting the molar ratio of water to surfactant [10].

Thermal decomposition

Thermal decomposition is a procedure mainly used in fabrication of semiconductor nanocrystalline and oxides in a non-aqueous environment. Magnetic nanocrystals are produced via thermal decomposition of organometallic compounds in organic solvents with high boiling temperature, and including stabilizing surfactants [11]. The reaction time and temperature are of essential factors to control dimension and morphology of the particles.

Hydrothermal method

Hydrothermal method is an approach based on the general phase transfer and separation mechanism taking place at the interface of the liquid and solid phases. The surface modification of the nanoparticles should be performed after the hydrothermal procedure is done [5].

Magnetic Separation

Separation via magnetic field has been broadly used in various areas such as catalysis, ecological restitution, medical diagnosis, drug delivery and molecular biology. Magnetic nanoparticles, specially superparamagnetic ones consist of magnetic core, and can be readily separated via an external magnetic field, as a result they can be used for recycling waste, for example, for restitution of heavy metals in wastewater [12]. The advantage of this method is not producing This is one of the methods where purification does not generate consequent waste and materials can be recovered. The mechanism that takes place in the magnetic field is through ionic exchange and weak forces.

Functionalization of MNPs

Beside the high surface to volume ratio of nanoparticles, they should be stable if they are disposed to air (for pure metal nanoparticles such as iron, cobalt and nickel) [5]. To reach this purpose, the particles are coated by polymers, surfactant, silica, carbon, or valuable metals like gold to be used for different applications. The coating process protects the core magnetic particle and it also adds functional groups to the particle to remove the water contaminant. The surface modification of magnetic nanoparticles can be done by functional groups such as proteins, polyphenols, carboxyl, hydroxyl and amino groups. These particles are covered by positively or negatively charged particles to reach higher stability [13].

Also fabrication of bimetallic nanoparticles has gotten a lot of attention, because they show improved stability, enhanced reactivity, and oxidation hinderance. The iron (Fe) plays the role of an electron donor in the reaction with the water pollutants and the noble metal is protected in the elimination of chlorinated aliphatic compounds [14].

Toxicity of Nanoparticles

The significant characteristics of magnetic nanoparticles such as size, surface to volume ratio, charge, morphology and coated surface affect the synergy at the interface between magnetic nanoparticle and living creatures. As a result the study of toxicity and compliance with biological organism should be developed to provide sustainable techniques for wastewater treatment accompanied by risk evaluation [15].

Finally some challenges such as MNP recycling, toxicity, and enhancement of reduction percentage of the water pollutants still remain as important issues to be studied.

Conclusion

In this paper, the elimination of water contaminants via magnetic nanomaterials of zero valent iron (Fe^0), magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3) have been explained. These materials have been applied in elimination of water contaminants with the help of their different characteristics such as surface functionalities (e.g., coating with polyphenols, amino acids, proteins, carbonyl, carboxyl, carbon, polysaccharides, and semiconductors) with required dimension, configuration and magnetic response. Magnetic nanomaterials seem to be very encouraging

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for the treatment of water and wastewater. The methods used for water treatment via these materials are rapid, safe, and environmentally friendly compared with other common treatment methods, and this exhibits them commercially competitive. Their magnetic property of this materials gives rise to facile separation from aqueous environment after distillation and can be reclaimed in frequent treatment series. Although, more research is necessary to commercialize this method, and also important features including accurate mechanism of the material function, and size and morphology control during the synthesis should be investigated. The magnetic nanoparticles and nanocomposites with high surface to volume ratio suggest more a better candidate for physical and chemical adsorption and therefore illustrate large reactivity that leads to their application in large scale elimination of water contaminants.

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