Magnetic Nanoparticle: Synthesis and Environmental Applications

Sneha S. Lunge, Shripal Singh and Amalendu Sinha

***Abstract*—**Magnetic nanoparticles (MNPs) are attractive to many researchers because of their wide-ranging applications. MNPs has been also applied for removal of toxic pollutants like Arsenic and Fluoride in contaminated water. In recent years, MNPs have attracted much interest and been widely used as sorbents due to properties such as high surface area, and exhibit super-magnetic properties. The magnetic property separation easy from aqueous solution by the application of external magnetic field. MNPs have been also used as catalyst in photocatalytic degradation of dyes and pollutants in water. There are different ways to prepare MNPs. In the present article, MNPs synthesized using various synthesis methods for various environmental applications have been explored.

***Keywords*—**Magnetic nanoparticles, MNPS, nano materials, synthesis

I. Introduction

MAGNETIC nanoparticles (MNPs) are attractive to many researchers because of their wide-ranging applications of data storage, magnetic fluids, adsorbent, catalysis, biotechnology, biomedicine and environmental remediation [1–4]. Several methods have been developed for synthesizing MNPs with different compositions. MNPs with appropriate modified surfaces have been widely applied in biomedical applications, such as diagnostic (magnetic resonance imaging and magnetic enhanced enzyme-linked immunoassay) and therapeutic (drug delivery and hyperthermia) applications. The magnetites have been studied for hyperthermia and considered as the novel environmental treatment [5]. The adsorbability of MNPs, applying for toxic pollutants (Arsenic and fluoride) in contaminated water, has also been demonstrated [6, 7]. In recent years, MNPs have attracted much interest and been widely used as sorbents due to properties such as high surface-to-volume ratio, short diffusion rate [8], highly dispersible in water and exhibit super magnetic properties. The latter property makes them separable from aqueous solution by the application of external magnetic field [9]. MNPs have been also used as catalyst in photocatalytic degradation of dyes and pollutants in water [10]. MNPs have also been used widely in biological applications like enzyme immobilization to stabilize the enzyme, biosensors etc [11].

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There are many various ways to prepare MNPs, which have been reported in other papers, such as mechanical grinding, laser ablation, sol-gel, templating and co-precipitation, etc.

However, most of these techniques involve process complexity and are less economic. As one convenient and cheap method, chemical coprecipitation method has the potential to meet the increasing demand for the direct preparation of MNPs. Development of MNPs are therefore a challenging area of research.

II. Nanomaterial - Synthesis And Processing

A. Mechanical grinding

Mechanical attrition is a typical example of 'top down' method of synthesis of nano materials, where the material is prepared not by cluster assembly but by the structural decomposition of coarser-grained structures as the result of severe plastic deformation. This has become a popular method to make nano crystalline materials because of its simplicity, the relatively inexpensive equipment needed, and the applicability to essentially the synthesis of all classes of materials. The major advantage often quoted is the possibility for easily scaling up to tonnage quantities of material for various applications.

Similarly, the serious problems that are usually cited are;

1. Contamination from milling media and/or atmosphere, and
2. to consolidate the powder product without coarsening the nano crystalline microstructure.

Mechanical milling is typically achieved using high energy shaker, planetary ball, or tumbler mills. The energy transferred to the powder from refractory or steel balls depends on the rotational (vibrational) speed, size and number of the balls, ratio of the ball to powder mass, the time of milling and the milling atmosphere. Nanoparticles are produced by the shear action during grinding.

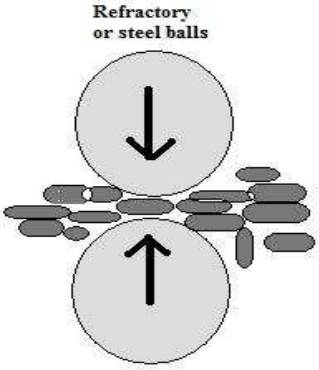

Fig.1 Schematic representation of principal mechanical grinding

B. Wet Chemical Method

In principle we can classify the wet chemical synthesis of nano materials into two broad groups:

1. The top down method: where single crystals are etched in an aqueous solution for producing nano materials, For example, the synthesis of porous silicon by electrochemical etching.
2. The bottom up method: consisting of sol-gel method, precipitation etc. where materials containing the desired precursors are mixed in a controlled fashion to form a colloidal solution.

C. Sol-gel process

The sol-gel process, involves the evolution of inorganic networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel). The precursors for synthesizing these colloids consist usually of a metal or metalloid element surrounded by various reactive ligands. The starting material is processed to form a dispersible oxide and forms a sol in contact with water or dilute acid. Removal of the liquid from the sol yields the gel, and the sol/gel transition controls the particle size and shape. Calcination of the gel produces the oxide.

Sol-gel method of synthesizing nano materials is very popular amongst chemists and is widely employed to prepare oxide materials. The sol-gel process can be characterized by a series of distinct steps.

D. Laser ablation

Laser ablation has been extensively used for the preparation of nanoparticles and particulate films. In this process a laser beam is used as the primary excitation source of ablation for generating clusters directly from a solid sample in a wide variety of applications. The small dimensions of the particles and the possibility to form thick films make this method quite an efficient tool for the production of ceramic particles and coatings and also an ablation source for analytical applications such as the coupling to induced coupled plasma emission spectrometry, ICP.

E. Co-precipitation method

Co-precipitation method is easy to do with the success rate from 96 to 99.9%. In this method, ferrous and ferric ions at the ratio of 1 to 2 in alkaline medium. Chemical co-precipitation can produced fine, stoichiometry particles of single and multicomponent metal oxides.

F. Template method

Templating is commonly employed for the controlled production of materials with ordered structure having desired properties. In the past, templates like aluminium oxide, carbon nanotubes, surfactants, polymer fibres, chitosan, cellulose, alginate and egg shell membranes have been employed.

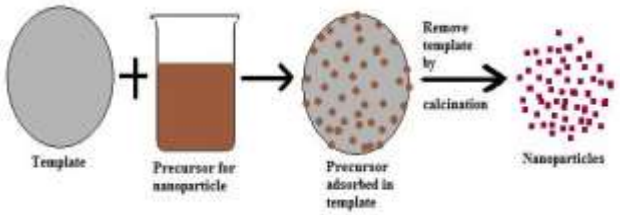

Fig.2 Schematic Representation of principal of Template method

III. Environmental Applications

A. Water and wastewater treatment

MNPs possess different chemical properties originating from the oxidation states of iron. Their capability and reactivity for contaminant removal are different. Yet, the removal performance can be influenced by various conditions, depending on the removal mechanisms. Knowing the removal mechanisms of these magnetic nanoparticles can justify the applicability of them in environmental applications.

MNPs have been used for removal of anions like arsenic, fluoride, chromium and cations like copper, nickel, mercury etc. from water and wastewater. MNPs are also reported for removal organic pollutants like phenol and dyes from wastewater. MNPs have been used as catalyst in photo catalytic degradation of dyes and organic pollutants.

B. Air pollution

Air pollution is another potential area where nanotechnology has great promise. Filtration techniques similar to the water purification methods described above could be used in buildings to purify indoor air volumes. Nanofilters could be applied to automobile tailpipes and factory smokestacks to separate out contaminants and prevent them from entering the atmosphere. Finally, nanosensors could be developed to detect toxic gas leaks at extremely low concentrations. Overall, there is a multitude of promising environmental applications for nanotechnology. Much of the current research is focused on energy and water technologies.

C. Environmental remediation

Environmental remediation includes the degradation, sequestration, or other related approaches that result in reduced risks to human and environmental receptors posed by chemical and radiological contaminants. The benefits, which arise from the application of nanomaterials for remediation, would be more rapid or cost-effective cleanup of wastes

IV. Conclusion

With developing different aspects of nanotechnology, the broader environmental impacts of that will also need to be considered. Such considerations might include models to determine potential benefits of reduction or prevention of pollutants from industrial sources. Nano science technology holds great potential for the continued improvement of technologies regarding environmental protection. MNPs due their easy separation properties have great potential in environmental applications.

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