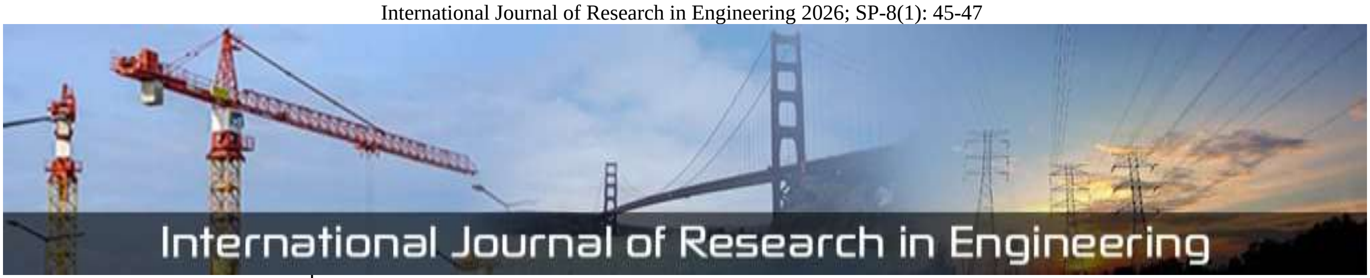

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Applications of surface functionalized nanoparticles

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Abstract
Nanotechnology has an impact on many scientific and technical fields, including industrial, biomedical, and environmental. Nanomaterials display unique characteristics owing to their extremely small and surface functionalization. The growing use of magnetic nanoparticles demands cost-effective methods for their synthesis that allow proper control of particle size and size distribution. The unique properties of magnetic nanoparticles include high specific surface area, ease of functionalization, chemical stability and superparamagnetic behavior, with applications in catalysis, data and energy storage, environmental remediation and biomedicine. The surfaces of nanomaterials can be coated with functional groups possess highly active components and providing sizeable surface areas. Functionalized nanomaterials are highly beneficial and possess superior properties compared to their traditional counterparts. The essential conditions for coating agents to be compatible with the coating is non- toxicity and biocompatibility. These properties include enhanced physical, chemical, mechanical and other features, which enable modified nanomaterials to surpass their conventional counterparts. They are increasingly being utilized for innovation and development in a wide range of fields. This review paper mainly emphasis on the fundamental of nanomaterial functionalization and their applications.

Keywords: Nanotechnology; Nanoparticles; Environmental; Biomedical

Introduction

In recent years, the research and development for nanotechnology has attracted significant interest and it is still the subject for investigation on its application. The fields of materials science, chemistry, physics, biology, and engineering have all benefited greatly from the study and utilization of nanotechnology and nanoscience, which is the study and application of extremely small objects. Currently, research into nanotechnology and nanomaterials is driven by scientific breakthroughs, deep scientific foundations, and scientific innovation. Nanoparticles (size less than 100 nm) possess unique characteristics including high reactivity as compared to microparticles and large surface area to volume ratio. The synthesis and surface functionalization of nanoparticles result their useful applications in the biomedical field [1-2]. Among various types of nanoparticles, magnetic nanoparticles offer some attractive possibilities in the biomedical field, which is due to the conservative storage of iron in cell and iron detoxification [3]. For biomedical applications, the particles should have the characteristic properties of biocompatibility and magnetization. Although pure metals are having a high value of magnetic saturation but these are highly toxic and very sensitive to the oxidation [4]. The iron oxides are inert towards oxidation than other metal oxides and also possess superparamagnetic properties. Thus, iron oxide nanoparticles show high potential for the use in biomedical applications. Among various forms of iron oxides magnetite (Fe_3O_4) was considered as the appropriate candidate for several applications such as magnetic fluids [5], catalysis [6-7], biomedicine [2], magnetic resonance imaging [8-9] as well as environmental applications [10-11], due to their biocompatibility [12] and relative ease to functionalize. Magnetite nanoparticles (MNPs) display magnetic properties and subsequently may be used as a cell-targeting agent by applying magnetic field. The physical, chemical and magnetic properties of these magnetite nanoparticles categorized these as ideal materials for biological as well as medicinal studies. The present review briefly highlights the applications of magnetite nanoparticles in the biomedical field.

General methods for the synthesis and surface functionalization of magnetite nanoparticles

During the last few years, a large number of research articles have published on the synthesis of magnetite nanoparticles, which usually describe the efficient methods to synthesize stable, shape and size controlled magnetite nanoparticles. The present review concisely discussed several methods including co-precipitation, micro-emulsion, and sol-gel etc. Among these, the co-precipitation method is probably known as the most effective and efficient chemical pathway to synthesize magnetic nanoparticles. It involves the addition of a mixture of salts of ferrous and ferric in the molar ratio 2:1 to the basic medium under oxygen-free environment [2]. This method used to produce nanoparticles to a larger extent, with control over the size and shape, which generally depend upon the pH, the ratio of Fe^{2+}/Fe^{3+}, types of salts used and the reaction temperature ionic strength of media. Additionally, another approach namely hydrothermal synthesis can also be used to synthesize highly crystalline and large particles. In hydrothermal synthesis, nanoparticles are synthesized by hydrolysis and oxidation reaction followed by the neutralization of mixed metal hydroxides. In this, only one ferrous source is used as a starting material to synthesize nanoparticles contrary to the methods mentioned above. Another significant method for the synthesis of iron oxide nanoparticles is microemulsion method. Lee *et al.* [13] reported the use of water-in-oil emulsions to synthesize magnetite nanoparticles. $FeCl_3$ and $FeCl_2$ were used as the source of iron. The synthesis of the magnetite nanoparticles was attained by mixing the two solutions comprising w/o emulsion in isooctane with Fe(III)/Fe(II) in one and NaOH in other. This method may be used significantly to prevent the agglomeration of nanoparticles and thus act as a nanoreactor for the size-controlled growth of magnetic nanoparticles. However, the morphology of the synthesized nanoparticles can be controlled by adjusting the pH of the reaction mixture. For practical uses, the surface of these nanoparticles must be functionalized to improve their biocompatible nature and to prevent their agglomeration. Bare magnetite nanoparticles possess hydrophobic surfaces. Due to which, these magnetite nanoparticles exhibits interactions among themselves and gets agglomerated to form clusters of particles. When the two large clusters approach each other, then both will get magnetized due to the second magnetic field of the neighborhood, results increased agglomeration. Thus, it is essential to shield the surface of bare magnetic nanoparticles. The shielding shells not only shield the surface of nanoparticles but can also be used to stabilize the nanoparticles.

Environmental Applications of surface functionalized nanoparticles

Environmental pollution is a significant cause of disease throughout the globe, but the dangers are disproportionately greater in developing nations due to poverty, a lack of investment in new technologies, and inadequate environmental regulations. Using nanoscale and size control, nanotechnology may be able to offer solutions to environmental problems. The application of nanotechnology to enhance air, water, and soil quality holds excellent promise. Detection and sensing of pollutants by the use of nanoparticles is improved, which aids in the development of new cleaning methods. Capping agents enhance the bioactivity of nanoparticles as the saturation bond caused by the capping agents on the nanoparticle's surface protects the particle from its surrounding environment. This makes it possible to manipulate the synthesis's nucleation and growth kinetics. The capping agents may also prevent the transport of additional reagents to the nanoparticle surface and may lower the toxic effects of metallic nanoparticles. Mahmoodi *et al.* reported the synthesis of magnetic ferrite nanoparticles-alginate composite and their use in removal of dye from colored textile wastewater [14]. A significant increase in efficiency of dye removal by above mentioned nanoparticles (MFN-alginate) was observed with increase in amount of alginate. This increase in efficiency may be attributed to the availability of more adsorption sites. Many researchers have reported surface modified iron oxide nanoparticles having an inner core of iron oxides and an outer covering of inorganic materials e.g. metals like silica, gold and gadolinium. Such metal coated IONPs not only offer the stability to the nanoparticles in solution but also help them to bind with various biological ligands. This property has been used in removal of dye from water. In this sequence, Chang *et al.* prepared hexadecyl functionalized magnetic silica nanoparticles (C_{16}/SiO_2- Fe_3O_4) for the removal of dye "Rhodamine 6G" under various conditions [15].

Biomedical Applications of surface functionalized nanoparticles

The property of magnetic separation has effectively applied for numerous biomedical as well as biological researches. For biomedical applications such as *in vivo* and *in vitro* studies, an ideal candidate must possess several characteristics such as low toxicity, biocompatibility, biodegradability, maintenance time, and magnetism to confine at the target. While, magnetite nanoparticles exhibit all mentioned properties and the superparamagnetic character which enables their easy separation by applying an external magnetic field. Thus magnetite nanoparticles referred as ideal candidate for biomedical applications. Currently, the growth of tailored nanoparticles is estimated to bring an innovation to the opportunities of their use in numerous biomedical applications. Polysaccharides like dextran and polymers including polyacrylamide and polyethylene glycol were commonly used to modify the nanoparticles for *in vivo* applications. Surface modification of nanoparticles by amphiphilic polymeric surfactants including poloxamines and poly (ethylene glycol) PEG and their derivatives, enhance the circulation time of blood by reducing the protein adsorption to the nanoparticles [16]. Recently, carbon coating has been used as a biocompatible material, which is due to the high capacity of carbon to adsorb. Gallic acid is a polyhydroxylphenolic compound which shows numerous antiviral, anticancer as well as antibacterial activities and hence can be used for numerous biological applications. Hyperthermia is a technique of using heat for the treatment of cancer [17]. Recently, various methods such as hot water bath, high-frequency radiation, magnetic fluid hyperthermia etc. were used to heat and destroy the tumor. As magnetite nanoparticles can be visualized by using MRI, so their use is superior among all methods. Normally, tumor cells are destroyed at high temperatures (>43^0C), while normal cells tend to survive even at high temperatures. However, the amount of heat produced can be influenced by nature of the used material and applied magnetic field. Magnetic resonance imaging (MRI) is one of the most promising non-imperious imaging techniques used in medical field. It is known to be the desired tool to practice for brain as well CNS (central nervous system) imaging and also used to detect tumors and evaluate cardiac function. MRI gives highly resolution images of soft tissue hence may be referred as a favorable technique for molecular and cellular imaging [18]. MRI contrast agents can help to clarify images and to allow better interpretation [19]. Nano-sized superparamagnetic iron oxide particles display an essential role as MRI contrast agents, as these were the first liver-specific contrast agents used [20].

Tissue repairing can be accomplished by using magnetic nanoparticles either by connecting, where natural or synthetic polymer modified magnetite nanoparticles are placed between two tissue surfaces to enhance the joining of tissue or through welding, and then heating is provided to connect tissues satisfactorily [21]. Nanoparticles such as gold [22] or silica modified [23] nanoparticles are very valuable tools for the tissue repairing technique. Magnetite nanoparticles can also be used to spot the principal cells of the body (stem cells) for the regeneration of tissues. Those principal cells work as usual storage space for new cells and provide growth to other particular cell types and can also be utilized for relocation purposes.

Conclusion

Nanoparticles are referred as chemically stable materials consequently being widely used in several biomedical fields as well as environmental applications. These were considered as a suitable candidate owing to their unique properties such as large size to volume ratio, adsorption property, insignificant toxicity, biocompatibility and catalytic behavior. This review paper briefly elucidates the mode for synthesis of these magnetic nanoparticles and their various applications in the environmental and biomedical field. This review emphasizes on some basic applications of magnetic nanoparticles such as dye adsorption, heavy metal removal, drug delivery, tissue repair, hyperthermia and MRI contrast agent.

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