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APPLICATIONS OF NANOTECHNOLOGY BASED ON IRON OXIDE

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ABSTRACT

Magnetic nanoparticles can be utilized for various purposes of public benefit owing to their specific properties. In last few decades magnetic Iron oxide nanomaterials have been developed extensively not only for researchers interest but also for many potential applications such as biosensing, drug delivery, magnetic resonance imaging, hyperthermia, catalysis, environmental remediation etc. This work outlines the developments in the field of prospective application of Iron oxide nanoparticles.

Keywords:- Application, Ironoxide, Magnetic, Nanomaterials

I. INTRODUCTION

Due to nanosize, high surface area to volume ratio and superparamagnetic property **[1-3]** researchers are focusing on synthesis and application of Iron oxide nanomaterials in recent years. It is reported that particle sizes, morphology, surface structure, magnetic behavior of nanomaterials is influenced significantly by synthesis methods and surface coatings **[4]**. Many researchers have been focusing their efforts on developing chemical and physical methods for the synthesis of Magnetic nanoparticles (MNPs) **[5]**. In recent times, various synthesis techniques have been explored to synthesize superior nanoparticles **[6]**, nano-ovals **[7]**, nanobelts **[8]** or any other nano-sized structures. Ironoxide nanoparticles (IONPs) are very unique in their usefulness owing to their simple synthesis, surface functionalization, and the capability to manage or control the matter on atomic level **[9,10]**. Since iron oxide nanomaterials are less toxic, chemically inert and biocompatible, they confirm a remarkable usefulness in association with biotechnology **[11]**. Applications of these nonmaterials in various fields depend on their shape, size and surface morphology.

II. NANOTECHNOLOGY

Nanotechnology deals with the study and control of matter at dimensions of approximately 1-100 nm **[12]**. Nanomaterials are the substances having size less than 100 nm in at least one dimension. Nanotechnology is an interdisciplinary science to a large extent and combines the laws of Physics, chemical processes and biological principles at the nano scale level.

The possibility of synthesis of nanosized products for the first time was connected with the well-known lecture called "There is a lot of space down there" of Mr. R. Feyman, delivered in 1959 at the conference of the American Physical Society. The term "Nanotechnology" was introduced for the first time by N. Taniguchi at the

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international forum on industrial production in Tokyo in 1974. In the second half of 1980s to the early 1990s many important discoveries were made which influenced the development of Nanotechnology.

Even long before the start of "Nonoera", people were using various nanosized objects. They consider that small particles of various substances exhibit properties different to the larger particles of same substances. But the accurate reason of this concept was not clear to them. In this way, people were dealing with Nanotechnology subconsciously without understanding that they are working with the nanoworld phenomenon **[13].**

Nanoparticles differ from large-sized materials as the number of atoms at the exterior surface is very high and have unique physical properties differing from corresponding bulk materials **[14]**. The physical properties of bulk materials e.g. resistivity, density, magnetization and dielectric constant are averaged properties. Many properties of bulk materials change as size is reduced up to nanolevel **[15]**.

III. IRON OXIDE NANOMATERIALS

3.1. Crystal structure of Iron oxides

There are some inorganic compounds made of iron and oxygen, they are known as Iron oxides. Iron forms overall sixteen oxides and oxyhydroxides **[16]** which find wide range of application from pigments in ceramic materials to use in thermite.

In the crystal structure of hematite, arrangement of O^{2-} ions is Hexagonal Close Packed in which Fe^{3+} ions occupy the octahedral sites (Fig. 1a). In magnetite and maghemite, arrangement of O^{2-} ions is Cubic Close Packed (Fig. 1b). In magnetite Fe^{3+} and Fe^{2+} both ions are present, Fe^{3+} ions are distributed at random among octahedral and tetrahedral sites, and Fe^{2+} ions occupy octahedral sites. It has an inverse spinel structure. **[17].** Maghemite also displays a similar spinel structure except the presence of vacant sites in the cation pattern. Fe^{3+} ions are arranged on two-thirds of the lattice sites in a regular fashion exhibiting two occupied sites followed by one vacant site **[16].**

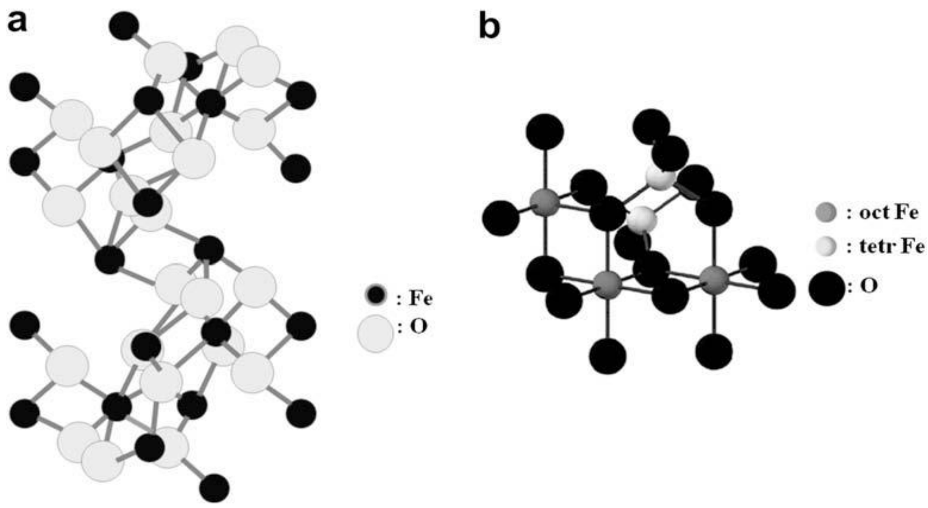

Figure 1: structure of (a) hematite and (b) magnetite crystals [18].

3.2. Ferrofluids

A steady colloidal homogeneous suspension of magnetic nanoparticles (around 10nm in size) in a suitable liquid either aqueous or non-aqueous termed as Ferrofluid or magnetic fluid **[19].** Iron oxide nanoparticles which have more saturation magnetization values and high magnetic susceptibility are preferentially utilized as magnetic particles for this purpose. Usually magnetite and maghemite have been used for this purpose **[16,20].** The magnetite nanoparticles are ideal for use owing to their higher saturation magnetization values **[21].**

IV. APPLICATIONS OF IRON OXIDE NANOPARTICLES

4.1 Drug Delivery

Drug targeting using IONPs has evolved as one of the novel tools for delivery of drugs in recent years. The nanoparticles can be delivered to the target area and fixed at a location where the medicine is discharged by applying MNPs along with an external magnetic field. This technology is termed as magnetic drug targeting **[22,23]**. This method of drug transport to a particular location can stop the side effects and also decrease the quantity of medication required. The surfaces of the nanoparticles being utilized for drug delivery are commonly capped with drugs, proteins, and genetic materials to attain their targeted release **[24,25]**.

4.2 Bioseparation

In biomedical research, specific biological units e.g., DNAs, proteins can be separated from their neighboring atmosphere using superparamagnetic (SPMs) colloids because nature of magnetization of SPMs in presence and absence of external magnetic field differs from each other. In this process, the biological units labeled with super paramagnetic colloids are separated by applying a magnetic field **[4]**. Due to their small size and high surface area, MNPs exhibit many superior characteristics compared with the conventional micrometer-sized resins or beads which are suitable for bioseparation purposes, such as good dispersability, fast and effective binding of biomolecules, and reversible and controllable flocculation. Hsiao et al. **[26]** designed C18-functionalized Fe_3O_4 nanoparticles not only to specifically trap phosphopeptides, but also nonphosphorylated peptides, both of which can be subsequently desorbed selectively by stepwise elution with different eluents.

4.3 Magnetic Resonance Imaging

Due to face-centered cubic arrangement of oxygen in maghemite and magnetite, electrons are allowed to shift between iron ions occupying the lattice tetrahedral and octahedral sites. It gives half-metallic properties to these molecules which are appropriate for magnetic resonance imaging (MRI) **[27]**.

Recently, Muller et al. **[28]** has broadly explained applications of superparamagnetic IONPs as a contrast agent. Kim et al. **[29]** synthesized ferrofluids coated with oleic acid surfactant and dispersed in a suitable carrier for bio-applications such as chitosan and found that it was useful for MRI contrast agents.

4.4 Hyperthermia

In cancer treatment magnetic nanoparticles can be used very effectively for hyperthermia treatment. Tumor cells are heated at temperature 41-45˚C by using superparamagnetic nanoparticles under an alternating magnetic field. At this stage tissue damage for normal tissue is reversible although the tumor cells are permanently damaged **[30]**. Some researchers have shown that magnetite cationic liposomal nanoparticles **[31,32]** and dextran-coated magnetite **[33]** effectively increase the temperature of tumor cells for hyperthermia.

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4.5 Catalysis Applications

There are a range of reactions involving transition metal catalysis which make use of catalytic sites implanted onto MNPs for example carbon-carbon cross-coupling reactions **[34,35]**, hydroformylation **[36]**, hydrogenation **[37]** and polymerization **[38]** reactions. Magnetite and hematite have been employed as catalysts in various types of industrially important reactions **[39-42]**, for example synthesis of NH_3 (the Haber process), the high temperature water gas shift reaction, and the desulfurization of natural gas. Owing to their specific semiconductor nature magnetite and hematite can catalyze oxidation/reduction reactions **[41,43,44]**. Hematite has also been used as a support material for gold as catalysts for the oxidation of carbon monoxide at low temperature **[44,45]**. Magnetite/carbon composites have been found useful for reducing the amount of undesirable N_2 in fuel oil **[44]**.

4.6 Environmental remediation

The technology based on Iron nanoparticle is supposed as the potent member of the first generation of nanoscale environmental technologies **[47,48]**. A few of the most demanding environment cleaning tasks can be provided cost-effective solutions by this technology **[49]**. Recently, Lee et al. **[50]** have synthesized 4,4-Difluoro-4-bora-3a,4a-diaza-s-indacene (BODIPY)-functionalized magnetic silica nanoparticles to make water and human blood free from Pb^{2+} with high affinity and selectivity. Their reported observations may help to develop a novel type of biocompatible scheme for the detection, recovery, and elimination of various heavy toxic metals from the human body by stabilizing the appropriate fluorescence receptors onto the surface of novel magnetic nanomaterials. It also showed that magnetic nanoparticles exhibit a great capability and effectiveness during the elimination of a variety of metal ions due to their high surface area as compared to micron-sized adsorbents. Nassar (2010) **[51]** studied the removal of Pb^{2+} ions and reported that the highest adsorption capacity for Pb^{2+} ions was 36.0 mg./g. by Fe_3O_4 nanoparticles. It was much higher than the results reported with low cost adsorbents. Peng et al. developed a novel magnetic adsorbent by immobilizing Saccharomyces cerevisiae on the outer surface of chitosan coated magnetic nanoparticles and employed for the removal of Cu^{2+} ions from aqueous solution **[52]**. Li et al. **[53]** analyzed the functions of nanocatalyst Superfine Fe_2O_3 nanoparticles during the removal of carbon monoxide. It can act both as a catalyst and as an oxidant. They observed that the effectiveness of nanoparticles as CO catalyst is much more than the micro-sized oxide powder and Fe_2O_3 nanoparticle can oxidize CO as an oxidant even in the absence of oxygen.

Iron oxide nanomaterials absorb visible light so can be utilized as a good photocatalyst **[54]**. The most commonly applied photocatalyst is TiO_2 which usually absorbs the Ultraviolet radiation having wavelength less than 380 nm owing to its large energy-gap of 3.2 eV **[55].** Fe_2O_3 is an appropraiate compound for photodegradation under visible light condition due to its low band-gap of 2.2 eV. Many Iron Oxides having Fe(III) oxides e.g. α-Fe_2O_3, γ-Fe_2O_3, α-FeOOH, β-FeOOH and γ-FeOOH have better photocatalytic effect and reduce toxicity by degrading organic pollutants **[56]**. Additionly, Fe_2O_3 can also be functional for sensitizing TiO_2 photocatalyst due to its small band-gap, **[55,57]**.

Magnetism is a specific physical characteristic that influences the physical properties of adsorbents in water and supports independently water purification technologies. Therefore, many researchers have extensively utilized magnetic separation in combination with adsorption procedure to decontaminate water and cleaning the environment **[58,59]**. IONPs are capable for wastewater treatment at industrial level due to their low cost, strong adsorption capacity, easy separation and enhanced stability **[60,61]**. The capacity of iron oxide nanomaterials to eliminate contaminants has been studied at both laboratory and field levels **[62,63].** The contaminant loaded magnetic nanoadsorbents can be separated easily from solution using an external magnetic field.

V. CONCLUSION

The use of ironoxide nanoparticles in various fields has been a beneficial development. Due to ease of synthesis, magnetic nature and biocompatibility, they turned out to be a useful tool for scientists. However, there are so many challenges which researchers are facing to provide efficient iron oxide nanoparticles for specific purposes. Therefore, future researches and studies should target to work on and solve these challenges.

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