Chapter 4

Study on Magnetic Materials for Removal of Water Pollutants

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Abstract

Water is a primary element for all living things, and we need water for each and every day-to-day activity related to agricultural, industrial, and domestic cares and, thus, its quality influences all aspects of human life including energy, food, health, and economy. Safe drinking water is our primary need to protect our life and thus developing efficient and affordable techniques for water treatment to access potable water to the humanity. Water pollution is one of the severe environmental and health problems worldwide. Pollutants in water can be of organic, inorganic, heavy metals, microbial, and radioactive species, which may be in different forms viz. suspended, dissolved, or dispersed materials. The water quality is mainly affected by industrial discharges, agricultural activities, mismanagement of hazardous materials, etc. Nowadays, nanotechnology offers the possibility of an efficient removal of water pollutants including metals, organic dyes, bacteria, parasites, etc. Magnetic nanomaterials like iron oxide (Fe_3O_4) are very promising materials used in water decontamination particularly for heavy metals and dyestuffs because of their ease of separation through external magnet, high surface area, unique morphology as well as their high stability. These materials can be used as adsorbent, photocatalyst, and coagulating agents for water remediation based on their composite materials or surface functionalities.

Keywords: magnetic nanomaterials, water treatment, water pollution

1. Introduction

Water, i.e., 2 mol of hydrogen and 1 mol of oxygen or simply called H_2O plays a vital role in our everyday life. Without water no one can think of life on earth. About 71% of earth is covered with water. Of that 71% water about 97% resides in oceans and only 3% of water is fresh water (**Figure 1a**) and of that 3% about 68.7% of freshwater is locked up in icecaps and glaciers (**Figure 1b**), and it is quite a surprising fact that almost all the remaining fresh water is below the ground. Of all the freshwater on the surface of earth only 0.3% is contained in fresh lakes, and rivers [1].

As the population is increasing day by day the water availability per capita is decreasing. So the challenge of limited amount of freshwater and its decreasing per capita availability is an issue of concern but another major challenge is water pollution that has not only environmental impact but also have a major effect on human health. As per the statistics 783 million people do not have access to clean and safe water worldwide [2]. Around 319 million people in Sub-Saharan Africa are without the access to improved reliable drinking water sources. One in nine people worldwide do not have access to safe and clean drinking water. 443 million school days are lost each year due to water-related diseases [3]. In developing countries, as much as 80% of illnesses are linked to poor water and sanitation conditions [4]. 2.6 billion people in the world lack adequate sanitation and which contributes to about 10% of the global disease burden [5]. Half of the world's hospitals beds are filled with people suffering from a water-related disease [6].

There are various type of illnesses due to water and are summarized in **Table 1**.

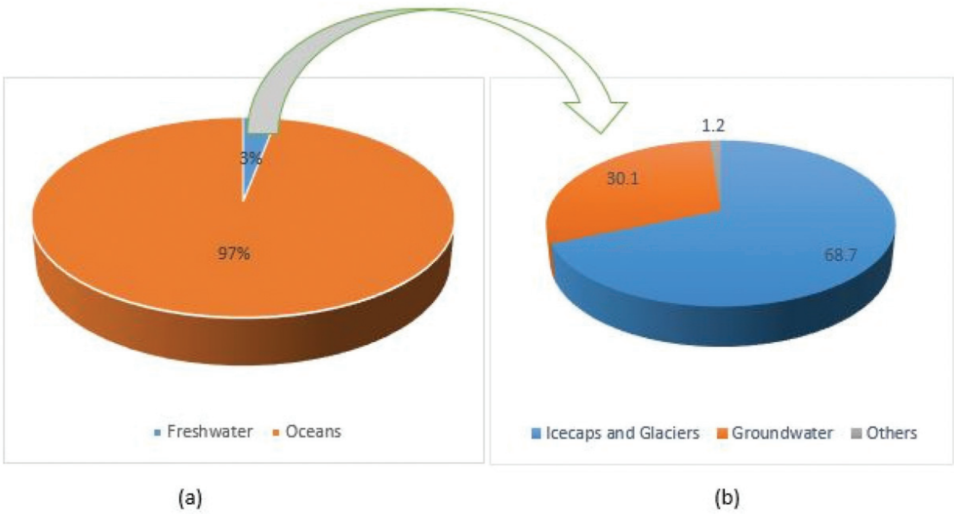

Figure 1. (a) Water distribution on the earth and (b) freshwater distribution on the earth.

Type of diseases	Source	Example	References
Water borne	Human or animal waste	Cholera, typhoid, and dysentery,	[7]
Water washed	Lack of clean water for washing	Skin and eye infections	[8]
Water based	Organism developed in water and then become parasite	Schistosomiasis	[9]
Water-related insect vector	Mosquitoes breed in water	Malaria and dengue	[9]

Table 1. Various types of illness due to water.

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As we have seen that the contaminated water has a very bad impact on human health even some heavy metals that if taken for long time it can cause cancer such as arsenic is considered as one the carcinogenic contaminant in water. After understanding the health issues related to contaminant water there is need to understand the source of contamination and major contaminants that pollute the water.

In recent years, magnetic materials have been potentially used for removal of water pollutants, particularly organic contaminates (dyes, chlorinated hydrocarbons, aromatics), pesticides, as well as heavy metals [10]. There are a large number of techniques available for water treatment for safe drinking water including adsorption, precipitation, solvent extraction, ion exchange, reverse osmosis, membrane separation, evaporation, and photocatalysis. The development of nanoscience and nanotechnology shows their potentiality in removing toxic elements from water bodies with better water treatment process. The design and development of nanomaterials which belong to the size range of 1–100 nm exhibiting unique properties as compared to the bulk materials leads to the enormous improvements in many sectors including, health, manufacturing, electronics, environmental remediation as well. The magnetic nanomaterials (paramagnetic or ferromagnetic or superparamagnetic) with tailored surface chemistry have already expanded their scope of application in water treatment. In this chapter, various processes of drinking water treatment and waste water treatment using advanced magnetic materials in removing toxic metal ions, organic and inorganic solutes, bacteria and viruses has been discussed.

1.1. Major sources of water contamination

There are many sources of drinking water and the main sources are ground water, lakes, canals, reservoirs, rain water, fog water and sea water. These sources are contaminated in different ways and broadly the source of contamination can be divided in to two categories:

- Direct sources or point sources
- Indirect sources or non-point sources

Direct sources basically include effluent from industries, treatment plants, refineries, factories, etc. However, indirect sources or non-point sources include the water contamination entering to the water body through a number of processes, e.g., while putting the fertilizers and pesticides to the agricultural field, the elements presents in the chemical percolates down to the groundwater and ultimately pollute the water.

1.2. Different types of water contaminants

There are various types of water contaminants, however in the following subsections organic contaminants, inorganic contaminants and pathogens are briefly discussed.

1.2.1. Organic contaminants

Organic contaminants present in drinking water create severe problem on human health. Pollution by organic chemicals in water bodies occurs by various mechanisms. Industrial waste containing various organic chemical contaminants pollutes the water bodies. Volatile organic compounds (VOCs), pesticides, phenolic compounds, phthalates, and nitrogen-containing compounds, are often detected in polluted water [11]. Many of these compounds have been found to be carcinogenic, even in very low concentrations. WHO Guidelines for drinking water quality, levels are set for 28 organic constituents (i.e., microcystin-LR, chlorinated alkanes, chlorinated benzenes and miscellaneous), 33 pesticides, and 9 disinfectant by-products, due to their health effects on humans [12]. It is noteworthy to mention that, occurrence of pharmaceutical and personal care products and perfluoroalkyl acids in aquatic environment has been recognized as emerging issue in environmental chemistry [13].

1.2.2. Inorganic contaminants

Inorganic contaminants include metals, salts and other compounds that do not contain carbon. Many of them are naturally occurring and should be considered as an integral part of those waters, e.g., calcium carbonate and bicarbonate in hard water. The metal ions such as Hg(II), Pb(II), Cr(III), Cr(VI), Ni(II), Co(II), Cu(II), Cd(II), Ag(I), As(V) and As(III) are toxic from eco toxicological point of view. Besides, the pollution by the radioactive elements is of major concern looking into their long-term hazardous impacts.

1.2.3. Pathogens

Pathogens such as bacteria, viruses and parasites may be present in very low concentration in drinking water; but cause many infectious diseases and are considered as one of the major risk factors with drinking water safety [14]. The pathogenic microorganisms enter in to water body through sewage discharge as a major source or through the wastewater from industries like slaughterhouses. Water-borne pathogens have been the causes of many disease outbreaks such as diarrhea, cholera, gastro-intestinal illness [15]. The recurrence of water-borne pathogens is due to a number of reasons like heavy water contamination, population explosion, change in potable water treatment methods, globalization of commerce and travel. It has been made possible to detect pathogen based water contamination to a large extent owing to the improved methods for detection and source tracking [16, 17]. The most serious health risk is related with ingestion of water which is contaminated with fecal matter and the discharge of wastewater into various ambient water bodies is what contributes to the multiplication of numbers of such pathogens (bacteria, viruses, protozoa and helminthes) [18].

2. Techniques for water treatment

Water treatment is defined as the removal of the above contaminants using some specific process. In most of the water treatment processes, conventional adsorption process with activated carbon is adopted and the adsorption capacity is substantially decreased in presence of high concentration of organic matters in water where the active sites are mostly occupied by these materials. In recent times, there are various technologies have been employed for the removal of water contaminants such as filtration (ceramic, bio sand, membrane, and activated carbon based filtration), heat and UV radiation, chemical treatment (coagulation-flocculation, chemical disinfection), and desalination (reverse osmosis, distillation). The various techniques in water treatment can categorized into following six classes [19]:

- Adsorption
- Biotechnology
- Catalytic processes
- Membrane processes
- Ionizing radiation processes
- Magnetically assisted processes.

There are specific advantages and disadvantages for a particular process. The nanotech based processes are promising option in current water treatment processes because of their target specificity, ease of separation, high adsorption per unit area, as well as less maintenance.

3. Magnetic materials for water treatment

There has been increased interest in using magnetic materials in water treatment which are basically composed of magnetic core of iron oxides organic compounds, carbon materials, etc. Recently, nanomaterials in different shapes, morphologies, forms, e.g., metal-containing nanoparticles, carbonaceous nanomaterials, zeolites, dendrimers, carbon nanotubes, nanofibers have been used for water purification [20]. However, the difficulty arises in using these materials is the separation of solid materials from liquid and which is more difficult as the particle size decreases in nanoscale. On the other hand, the using of magnetic, particularly the magnetic nanoparticles (MNPs) materials have the advantage of magnetic filtration in separation of solid from liquid and are more efficient [21].

However solid/liquid (S/L) separation is more difficult as the particle size decreases. On the other side, in case of magnetic sorbents based on Fe oxides, the magnetic filtration may be applied for S/L separation. Furthermore, the removal of particles from solution with the use of magnetic fields is more selective and efficient (and often much faster) than centrifugation or filtration (Yauvuz et al.) [21]. Here are the advantages of using MNPs adsorbent for water treatment processes:

- Small size and thus high surface to volume ratio
- Solid/liquid separation through magnetic filtration is selective, faster than centrifugation and filtration techniques
- Reusability
- Greater biocompatibility
- Magnetic separation

3.1. Different types of magnetic materials for water treatment

Different types of magnetic materials have been synthesized and designed for development of advanced materials and applied effectively in widespread uses such as biomedicine, magnetic resonance imaging (MRI), catalysis, spintronics, robotics, engineering, environmental remediation, etc. [22] There are different synthesizing methods viz. co-precipitation, solvothermal, hydrothermal, microemulsion, sonochemical, etc. which determine their particle size, distribution, morphology, surface functionality, and magnetic properties and in turn of their various application [22]. Magnetic materials are made from mixtures of metals of iron, cobalt, nickel, and alloys and their oxides (of the type MFe_2O_4, where M is a metal). Out of these materials, iron (zero valent iron) and its oxides, i.e., usually γ-Fe_2O_3 (maghemite) and Fe_3O_4 (magnetite) nanoparticles have attained significant interest in recent years and have been used for water treatment processes. The various composite magnetic materials such as Fe_3O_4@C [23, 24], Fe@SiO_2 [25], Fe_3O_4@TiO_2 [26], Fe_3O_4@PPO (poly(propylene oxide)), PEO (poly(ethylene oxide) [27], Fe_3O_4@PDA (polydopamine) [28], Fe_3O_4@PNIPAM (poly(N-isopropylacrylamide)) [29], Fe_3O_4@MIPs (molecularly imprinted polymer-encapsulated particles) [30], Fe_3O_4@CNTs (multi-walled carbon nanotubes) [31], Fe@CS (carbon spheres) [32], Fe/iron oxide-oxyhydroxide/rGO (grapheme) [33], etc. have been used for environmental applications. Singh and his co-workers synthesized a series of magnetic nanocomposites such as $CoFe_2O_4$–ZnS [34], Fe_3O_4@GTPs (green tea polyphenols) [35], Fe_3O_4–Cr_2O_3 [36], $CoFe_2O_4$-Cr_2O_3-SiO_2 [37] and applied for wastewater treatment.

In addition to their suitable magnetic properties, i.e., ferrimagnetic, ferromagnetic and superparamagnetic (nanoparticle size less than 10 nm), their synthesis procedure is simple and cost-effective and they can be easily functionalized as desired for many applications. The size and shape and magnetism of these magnetic materials can be easily controlled based on their application and thus they can be easily dispersed in liquid medium and their stability can be retained for multiple uses. Moreover, these materials are non-toxic or less toxic, chemically inert, thermally stable as well as biocompatible.

3.2. Use of magnetic materials for clean water technology

Appearance of water pollution as a global threat demands the development of low-cost and reliable materials for effective waste water remediation. The magnetic materials have been used for clean water technology for both in laboratory as well as field scale [38, 39]. In recent years, iron oxide nanomaterials have been used as adsorbent or immobilizing agent and photocatalyst or the both depending on nature of contaminants in water [40].

3.2.1. MNPs for the removal of metals

Heavy metal contamination in water such as cadmium, zinc, lead, chromium, nickel, copper, vanadium, platinum, silver and titanium due to industrial activities is significantly increasing which is detrimental to human beings and animals. Magnetic nanomaterial adsorbents have been potentially used for removal of metallic ions such as Cr(VI), Cu(II), Co(II),Cd(II), As(V), As(III) and Hg(II) in water [41, 42] which are more effective as compared to micron size particles. The magnetic chelating resin based materials have been used for effective removal of Cu(II), Co(II), and Ni(II) ions [43]. The magnetic hydrogels based on 2-acrylamine-2-methyl-1-propansulfonic acid can be used for removal of many heavy metal ions such Cd(II), Co(II), Fe (II), Pb(II), Ni(II), Cu(II) and Cr(III) from water in repeated cycles [44]. The Cu(II) can also be effectively removed by functionalized mesostructured silica containing magnetite [45]. The acrylate-based polymer composites with magnetite can be used in selective removal of heavy metals from water (selectivity: Cu > Cr > Zn > Ni) [46]. Layered double hydroxide (LDH) prepared from Fe^{3+} and Ni^{2+} shows good adsorption of As and subsequent magnetic separation [47]. The magnetic zeolite composites are used for decontamination of heavy metals from water [48]. The composite materials of mesoporous magnetic MCM-41 with aminopropyls are used for selective removal of As(V), and Cr(VI) in presence of Cu(II) [49].

3.2.2. MNPs for removal of organic contaminants

Magnetic nanoparticles are used as an adsorbent for the removal of various dyes and dyes stuff from aqueous solution. Removal of dyes from waste water has become a serious issue of concern because of its harmful impact on human. Dyes basically can be classified in to two categories, i.e., anionic dyes and cationic dyes.

3.2.3. MNPs for the removal of anionic dyes

Long et al. [50] synthesized Fe_3O_4@catechol/polyethylenimine (PEI) nanoparticles and tested for adsorption of three different kind of anionic dyes, i.e., methyl blue, orange G and amaranth and found the maximum adsorption capacities of 344.8, 192.3 and 146.2 mg/g, respectively. Saksornchai et al. [51] synthesized magnetite (Fe_3O_4) coated with cetyltrimethylammonium bromide (CTAB) and tested for the adsorption of anionic dye Congo red (CR) removal. They found maximum adsorption capacity for CR dye to be 93.46 mg/g. Faraji et al. [52] synthesized triazine-based nitrogen-rich network-modified magnetic nanoparticles were synthesized for the adsorption of methyl orange. Sahraei et al. [53] reported the synthesis of magnetic bio-sorbent hydrogel beads based on modified gum tragacanth/graphene oxide for the removal of heavy metals and dyes from water. They found the adsorption capacity of 101.7 mg/g for Congo red dye. Ge et al. [54] fabricated Fe@MgO magnetic nanocomposites for the removal of heavy metal ions and dye from water. They found that the synthesized nanocomposite showed excellent adsorption capacity of 6947.9 mg/g for methylene orange. Wu et al. [55] fabricated multi-functional magnetic nanoparticle core covered with polyethylenimine (PEI) derived quaternary ammonium compounds (QAC) corona through electrostatic attraction for the removal of dyes and metal ion adsorption. The adsorption results corresponding to synthesized nanoparticle showed the maximum adsorption capacity of 653 mg/g for AF as a representative of dyes. Konicki et al. [56] synthesized Fe@graphite core shell nanocomposite for the removal of anionic dyes from aqueous solution. The synthesized nanoparticles were tested for the adsorption of two anionic dyes namely acid red 88 (AR88) and direct orange 26 (DO26) and the maximum adsorption capacity was found to be 63.7 mg/g and 42.7 for AR88 and DO26, respectively. Zhang et al. [57] synthesized the Fe_3O_4 nanoparticle modified with 3-glycidoxypropyltrimethoxysilane (GPTMS) and poly-lysine (P-Lys). They found that the synthesized MNPs could effectively remove anionic dyes including methyl blue (MB), orange I (OR-I), amaranth (AM) and acid red 18 (AR-18) from water solution.

3.2.4. MNPs for the removal of cationic dyes

Cationic dyes are most toxic because they can easily interact with negatively charged cell membrane surfaces, and also they can enter in to the cells and can concentrate in cytoplasm (Bayramoglu et al.) [58]. Ge et al. [59] have studied the adsorption of cationic dyes such as crystal violet, methylene blue and alkali blue 6B from aqueous solutions by use of polymer-modified magnetic nanoparticles. The cationic dyes could be quickly removed from water solution with high efficiency at pH 5–12. More significantly, the MNP showed high efficiency as a reusable adsorbent for fast and convenient removal of cationic dyes from water solution. Yan et al. [60] have synthesized full biodegradable magnetic adsorbent based on glutamic acid modified chitosan and silica coated Fe_3O_4 nanoparticles for removal of three different kinds of cationic dyes, methylene blue, crystal violet and cationic light yellow 7GL, from aqueous solutions. Chen et al. [61] have prepared magnetic adsorbent by fabrication of chitosan/polyacrylic acid multilayer onto magnetic Fe_3O_4 microspheres for removal of adsorption of two cationic dyes, methylene blue and crystal violet from aqueous solution. Amiri et al. [62] synthesized cobalt ferrite silica magnetic nanocomposite for the adsorption of Malachite green dye and found the adsorption capacity of 75.5 mg/g for that dye. Li et al. [63] synthesized wettable magnetic hypercrosslinked microporous nanoparticle for the water treatment. The synthesized nanoparticle consists of microporous organic polymer which combine sodium acrylate functionalized hypercrosslinked polymer with magnetic Fe_3O_4 nanoparticle to form a hybrid. They tested the synthesized hybrid for the adsorption of Rhodamine B dye and found the maximum adsorption capacity of 216 mg/g. Singh et al. [64] had synthesized the superparamagnetic nanoparticles coated with green tea polyphenol by wet chemical method. They found that the particles have a very high adsorption capacity of (7.25 mg/g) for removal of methylene blue (MB) dye in wastewater treatment. Li et al. [65] synthesized magnetic peach gum bead bio-sorbent for the adsorption of MB dye and found the maximum adsorption capacity of 231.5 mg/g.

3.2.5. MNPs for the removal of pharmaceutical products

The presence of pharmaceuticals such as antibiotics, anticonvulsants, antipyretics drugs, hormones in surface and ground water possesses a major environmental challenge. Their contamination even at trace amount is a serious concern to the aquatic organisms as well.

Attia et al. [66] synthesized magnetic nanoparticles coated zeolite for the adsorption of pharmaceutical compounds from aqueous solution. They found that the synthesized magnetic nanoparticles can remove more that 95% of PPCPs in 10 min. Reddy et al. [67] reviewed spinal ferrite nanoparticles and found that SF and its derivatives can be used for remediation of various pollutants. Nadim et al. [68] Synthesized gallic acid coated magnetic nanoparticles (GA-MNP) and used as a photocatalyst for degradation of meloxicam; a commonly prescribed nonsteroidal anti-inflammatory drug.

Recently, M. Hayasi and his coworker described the use of magnetic poly (styrene-2-acrylamido-2-methyl propanesulfonic acid) (St-AMPS) as adsorbent for removal of the pharmaceuticals viz. ceftriaxone sodium, diclofenac sodium, and atenolol from water [69].

Liu [70] discussed the use of various magnetic nanoparticles (MNPs) in pharmaceutical removal from waste water their recent review which are outlined below (**Table 2**).

3.2.6. MNPs for removal of pathogens

Xu et al. [82] demonstrated that poly-allylamine-hydrochloride (PAAH) stabilized magnetic nanoparticles are powerful tools to remove pathogenic bacteria from drinking water with high efficiency and no significant toxicity was observed in the MNPs treated water. Over 99.5% of the pathogens (four main pathogens viz. *Escherichia*, *Acinetobacter*, *Pseudomonas* and *Bacillus*) can be removed when the bacterial count was less than 105 CFU/mL.

Zhang et al. [83] synthesized magnetic nanoparticle coated with Cu doped MgO through a hydrophilic carbon layer (Fe_3O_4@C@MgO-Cu). They found its potential application as disinfectant in water purification by examining the antibacterial activity of the Fe_3O_4@C@MgO-Cu composite toward Gram-negative *Escherichia coli* and Gram-positive *Staphylococcus aureus*.

Zhang et al. [84] synthesized magnetic poly-N,N′-[(4,5-dihydroxy-1,2-phenylene)bis(methylene)]bisacrylamide) (POHABA)-based core-shell nanostructure on the Fe_3O_4 core surface (Fe3O4@POHABA). The magnetic nanocomposite, Fe_3O_4@POHABA can be used in domestic water treatment against bacterial pathogens.

Rana et al. [85] synthesized ferromagnetic Ni-doped ZnO nanoparticles and applied as an antibacterial agent to control the growth of bacterial pathogens. They found the as synthesized material to be very effective against water related bacteria such as *E. coli* and *V. cholera*.

Magnetic materials used	**Pharmaceuticals present in water**	**Processes involved for decontamination**	**References**
Nano zero-valent iron (nZVI)	Carbamazepine	Adsorption, chemical degradation (Fenton oxidation)	[71]
Nano zero-valent iron (nZVI) and PEG and zeolite supported nZVI	Amoxicillin, ampicillin	Adsorption	[72]
Zero valent iron (ZVI)	Carbamazepine	Chemical degradation	[73]
	Diazepam	Chemical degradation	[74]
Maghemite (Fe_2O_3) core confined in a silica porous layer	Atenolol, gemfibrozil, and sulfamethoxazole	Adsorption	[75]
MFe_2O_4 (M = Fe, Mn, Co, Zn)	Tetracycline, oxytetracycline, and chlortetracycline	Adsorbent	[76]
$MnFe_2O_4$/(activated carbon)AC	Sulfamethoxazole	Adsorption	[77]
$MgFe_2O_4/\gamma\text{-}Fe_2O_3$	Minocycline	Adsorption	[78]
Fe_3O_4 MNPs in ultrasound (US)/H_2O_2 system		Sono-degradation	[79]
Fe_3O_4@α-MnO_2 microspheres	Ciprofloxacin	Catalytic degradation	[80]
Fe-ZnO	Diclofenac	Photocatalytic degradation	[81]

Table 2. Magnetic nanomaterials used for removal of pharmaceuticals.

Shukla et al. [86] synthesized the iron oxide nanoparticles coated with chitosan oligosaccharide and used for the removal of pathogenic protozoan cysts, entamoeba cyst (which causes amebiasis) from water. They found that *E. histolytica* can be efficiently captured using the magnetic nanoparticles from contaminated water.

Zhang et al. [87] synthesized Fe_3O_4 nanoparticles surrounded with polyethylenimine-derived corona and found to be efficient in capturing the pathogens and heavy metals.

Zhan et al. [88] synthesized the amine-functionalized magnetic nanoparticle (Fe_3O_4-SiO_2-NH_2) and used for rapid removal of pathogenic bacteria and viruses. The magnetic materials can be effectively used to capture a wide range of pathogens including various bacteria such as *S. aureus*, *E. coli* O157:H7, *P. aeuginosa*, *Salmonella*, and *B. subtilis*.

Park et al. [89] developed a novel magnetic hybrid colloid (MHC) decorated with varying sized Ag nanoparticles. The MHC was prepared as a cluster of superparamagnetic Fe_3O_4 coated with silica shell. The MHC decorated with the Ag nanoparticle of 30 nm size (Ag30@MHC) exhibited the highest antimicrobial efficacy toward *E. coli* CN13 (6-log reduction) and the bacteriophage MS2 (2–3 log reduction).

4. Magnetic water treatment

Magnetic water treatment (MWT) is a new technique which is promising in environmental remediation in addition to its increased application in the area of medicine, agriculture and industrial process. The water molecules acquire unique physicochemical characteristics under the influence of the magnetic fields (MFs). It is a non-chemical method and the water molecules undergo change from their cluster of many loosely bound water molecules into very small, uniform and hexagonally organized clusters of molecules under the magnetic treatment [90]. These features of the magnetized water prevent the polluting agents to enter in to its cluster and also make their easy passage through the cells of plant as well as of animals. Moreover, the MFs have antimicrobial activity on water. Therefore, the magnetized water molecules depict as bio-friendly and eco-friendly compounds to environmental management as well as to plant and animal cells.

5. Sustainability of magnetic nanoparticles

While taking sustainability in to consideration there are various factors over which it depends. Important factors include environmental impact on use of MNPs, toxicity associated with the MNPs, reusability, reactivity, adsorption capacity, biocompatibility, stability, etc. For example, uncoated nanoparticles are associated with some toxicity while coating can help them to make non-toxic. Similarly, their regeneration and reusability are the main factors for making them technically more viable and economically sustainable materials for commercial uses.

6. Conclusions

In this chapter the removal of water pollutants by using magnetic materials of zero valent iron, magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3) as adsorbent, photocatalyst and coagulants have been described. The MNPs have been used in removal of water pollutants through their various surface functionalities (e.g., coating with polyphenols, amino acids, sugars, alkaloids, terpenoids, proteins, carbonyl, carboxyl, carbon, polysaccharides, and semiconductors) with desired size and shapes, and magnetic behavior. Looking in to the fast development of magnetic materials in different technological and scientific fields, magnetic nanomaterials appear to be extremely promising for water and wastewater treatment. The waste water treatment methods using these materials are fast, non-toxic, and eco-friendly as compared to the available physic-chemical treatments which make it attractive for materializing commercially. Their magnetic nature makes them attractive for waste water treatment because of their easy separation from aqueous medium after purification and can be reused in repeated treatment cycles. However, research for bulk production, controlling morphology, optimizing surface functionality and their stability, and biocompatibility should be essentially considered prior to commercial application from laboratory scale. Moreover, further studies needs to be addressed to detail mechanism of magnetic nanomaterials in water treatment. The magnetic nanoparticles and their composites with their high surface to volume ratio offer more surfaces for chemical as well as physical adsorption and thus show high reactivity which gives the prospects of using these materials in large scale removal of emerging water pollutants.

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