Volume 1, Issue 1, January 2014 ISSN: 2348-8565 (Online)

International Journal of Modern Engineering and Research Technology

Website: http://www.ijmert.org Email: editor.ijmert@gmail.com

Applications of Iron Oxide Based Nanoadsorbents in Water Remediations

Dr. Priyanka Agrawal
Assistant Professor,
Hitkarini College of Engineering & Technology,
Jabalpur (M.P.) [India]
E-mail: agrl_priya@rediffmail.com

ABSTRACT

Environmental nanotechnology is considered to play a key role in the shaping of current environmental engineering and science. Looking at the nanoscale has stimulated the development and use of novel and cost-effective technologies for remediation, pollution detection, catalysis and others. Iron oxide based nanoparticles (FeONPs) alone are suitable for a broad spectrum of applications, but the low stability and heterogeneous size distribution in aqueous medium represent major setbacks. These setbacks can however be reduced or diminished through the coating and functionalization of FeONPs with various chemical groups of polymers, especially biopolymers such as polysaccharides and proteins. In this review the synthesis and applications of the bionanocomposites of iron oxide will be discussed, in view of their recent and future water remediation and biotechnological applications.

Keywords:— *Iron oxide, biopolymers, nanoparticles.*

I. INTRODUCTION

The theme of this review is clean water, one of the essential companions of life on earth. The molecular as well as macromolecular functions of making life possible are carried out using water. The earliest form of life appeared in sea water about 3.5 billion years ago and was transferred to land only 380 million years ago. Despite this transfer to land, an ocean, in terms of fluidic composition, continues to exist within us. Clean and fresh water is essential for the existence of life. The evolution of civilization has always revolved around water. Leonardo Da Vinci had described water as “the vehicle of nature” (“vetturale di natura”)[1].

Saving water to save the planet and to make the future of mankind safe is what we need now. With the growth of mankind, society, science and technology our world is reaching to new high horizons but the cost which we are paying or will pay in near future is surely going to be too high. Among the consequences of this rapid growth the environmental disorder with pollution is a big problem [2].

The objective of this review article is to review of challenges in drinking water purification. Thereafter, the surface modification of iron oxide with various functional groups present on biopolymers is briefly discussed. Thereafter, a few of the methods of nanocomposites synthesis for drinking water purification are summarized. This review will focus on the current applications of biopolymers as agents for the surface modification of FeONPs, and the present and future perspectives of these nanostructures for biotechnological applications.

II. DRINKING WATER PURIFICATION — CHALLENGES

With the evolution of human civilization, our understanding of pure drinking water underwent dramatic changes. In early civilizations, the commonly practiced measure for purity was the taste of the water.

Many bodies such as USEPA, WHO, and EU have played a key role in developing regulations for many toxic species found in drinking water. Looking at some of the information provided by such bodies Figure 1, a few conclusions can be drawn.

- Most of the regulated chemicals fall in the organohalogen group.
- Organochlorine pesticides and halogenated organics continue to remain on the USEPA radar for future regulative activity.
- The other major contributors to the list are metals, inorganic salts and micro-organisms.
- Regulatory coverage of the USEPA for safe drinking water has increased over four times since its inception (in 1974), with revisions in maximum limits for many contaminants.

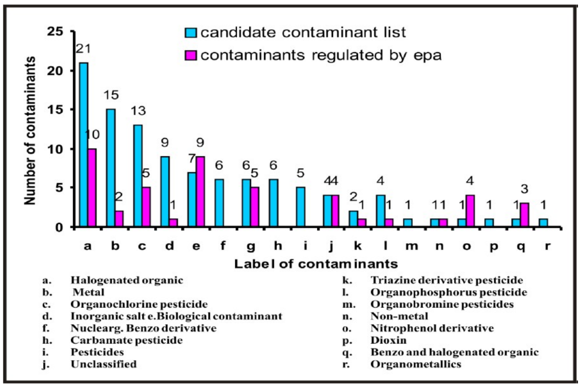


Figure 1: Category-wise distribution of contaminants regulated by USEPA and future contaminants[3]

Table 1 Review of major drinking water contaminants, their health impacts and a few associated events (compiled from multiple sources on the World Wide Web[1].

Major pollutant	Origin	Permissible limits	Affected countries	Population at risk	Health effects	Specific incidents
Pesticides	- Farming, ffluents, home use DDT:	1 ppb; Carbofuran: 40 ppb; Simazine:	US, Kenya, Egypt, India, European Union, Africa, China, Australia	Poisoning: 28 million agricultural workers in the developing ountries. ~18,000 deaths	Cancer, cardiovascular/ reproductive/neurological disorders, liver/kidney problems	Pesticide contamination in soft drinks, the Union Carbide Bhopal tragedy (India)
Halogenated organics	Chlorination, effluents, home insecticide	CCl4: 5 ppb; TCE: 5 ppb; TTHMs: 80 ppb	Japan, Central Asia, Arabian Peninsula, Sweden, Poland, Germany, USA, Egypt, China	~180 million people in US consume chloraminated water	CCl4: High toxicity to liver and kidney, carcinogenic. TCE: Lung/liver tumor	25 million pounds of TCE were released into the U.S. environment by manufacturing plants in 1995
Fluoride	-Geological origin, mineral weathering, coal mining	- 2 ppm	Asia, Mexico, Australia, Argentina, Africa, New Zealand	62 million (India)	Dental and skeletal fluorosis, Muscle fibre regeneration, nervous system malfunction	In 1999, a union of 1200 scientists, doctors and lawyers announced their opposition to water
Arsenic	Geological origin	- 10 ppb	Bangladesh, India, China, Pakistan, Nepal, Myanmar, Vietnam	65 million (Asia)	High blood pressure, glucosuria, hyperpigmentation,	1 in 100 people (Conc: 0.05 mg/l) and 10 in 100 people (Conc: 0.5 mg/l) die due to cancer in
Mercury	Industrial pollution, - dental filling, Food (fish)	- 2 ppb	Indonesia, China, Africa, Philippines, Japan, Kazakhstan, USA, Brazil, Australia, Taiwan, EU	~630,000 infants are born with high Hg content in the blood every year (USEPA)	Neurotoxicant, tremors, respiratory failure, gastrointestinal failures, and kidney damage	~30% of the mercury in US comes from abroad e.g., China - Unilever plant, Kodaikanal (India). Minamata, Niigata
Lead	- Old piping lines, mineral weathering, paint	15 ppb	Egypt, EU, USA, Thailand, China, Cambodia	N300,000 US children and 65% of Shanghai children have high lead concentration	Delays in physical/mental development, Kidney problem, high blood pressure	- Incidence of Gout due to leaded wine and rum - Use of lead in paints and discharge in environment - Use of lead in paints and discharge in nvironment

To provide a larger overview of the extent of the drinking water contamination, a consolidated summary of major contaminants is outlined in Table 1. It is quite clear that drinking water contamination has reached global levels in terms of the size of the population impacted.

A number of contaminants such as lead and pesticides are affecting water supplies globally due to their widespread use; pollutants of geochemical origin such as arsenic and fluoride are currently found in selected countries. In addition, the biggest class of contaminants affecting drinking water is microorganisms. Every year, 1.8 million people die from diarrheal diseases (including cholera); 90% are children under five, mostly in developing countries. Worldwide, 1 billion people lack access to safe drinking water, 2.4 billion to adequate sanitation. Improved water supply reduces diarrhea morbidity by 6% to 25%; improved sanitation reduces it by 32%. However, improving quality is a difficult task in areas where the risk of contamination is high. For example, one drop of oil can render up to 25 l of water unfit for drinking.

2.1. Nanotechnology–enabled water treatment

Nanotechnology can enable a distributed water reuse and treatment paradigm and offer leapfrogging opportunities to obviate concerns of water quality degradation within distribution networks, alleviate dependence on major system infrastructure, exploit alternative water sources (e.g., recycled new water) for potable and agricultural use, and abate energy consumption. This vision may be particularly appropriate for developing countries that face rapid degradation of water quality with increasing pressure for cleaner water to meet more stringent environmental, public health and food safety standards[4].

- This provides many advantages to drinking water purification.
- Effective contaminant removal even at low concentrations.
- Less waste generation post-treatment as less quantity of nanomaterial will be required vis-à-vis its bulk form. This happens since more adsorbent atoms/molecules are present per unit mass of the adsorbent and thus are actively utilized for adsorption.
- Novel reactions can be accomplished at the nanoscale due to an increase in the number of surface atoms (i.e. surface energy), which is not possible with the analogous bulk material. An example of one such process is the use of noble metal nanoparticles for the degradation of pesticides which can't be done by noble metals in their bulk form.

2.2. Introduction to Nanotechnology

The field of nanotechnology involves understanding and controlling matter at the molecular or atomic level where materials, due to their small scale, exhibit unique properties and behaviors when compared to the same material in a larger form (e.g., silver, copper, iron)[5]. The nanoscale is approximately 1 to 100 nanometers (nm), which is equal to one billionth of a meter. For comparison, an average bacteria cell is approximately 1,000 nm in diameter, there are 10 million nanometers in a centimeter and there are 25.4 million nanometers in an inch [6, 7]. Figure 1.3 shows an example of the size scale that nanotechnology works with. An industry-wide definition for nanomaterial has not yet been agreed upon. However, the British Standards Institution, the American Society for Testing Materials and the Scientific Committee on Emerging and Newly-Identified Health Risks have adopted the definition to be any material with *one* dimension under 100nm[8]. Within this group of materials are nanoparticles, which are defined by the International Organization for Standardization[9] as materials with at least *three* dimensions between 1 and 100nm.

Just how small is nano ?

Name	Abbrev.	Sci. Unit	Representative objects with this size scale
metre	m	100	Height of a 7-year-old child.
deci-	dm	10^{-1}	Size of our palm.
centi-	cm	10^{-2}	Length of a bee.
milli-	mm	10^{-3}	Thickness of ordinary paperclip.
micro-	μm	10^{-6}	Size of typical dust particles.
nano-	nm	10^{-9}	The diametre of a C60 molecule is about 1 nm.
pico-	pm	10^{-12}	Radius of a Hydrogen Atom is about 23 pm.
femto-	fm	10^{-15}	Size of a typical nucleus of an atom is 10 fm.
atto-	am	10^{-18}	Estimated size of an electron.

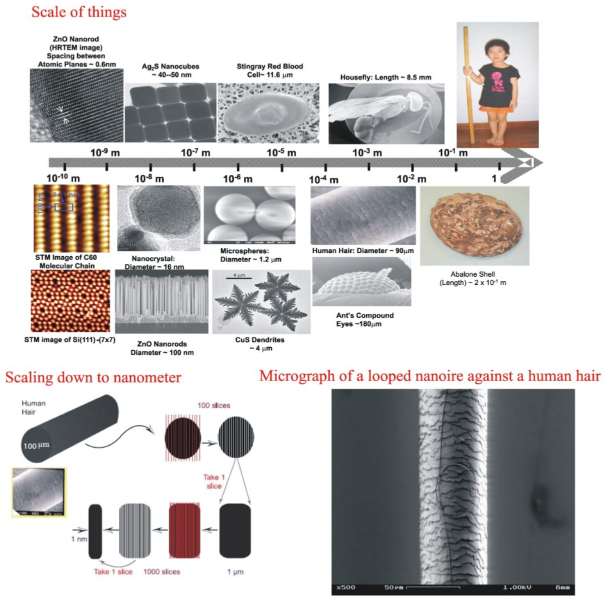


Figure 1.3 Size scale of nanotechnology

The characteristics that make most nanoparticles qualitatively different from larger particles is their large surface areas relative to their volumes and/or higher natural reactivity of the reactive surface sites[10]. Figure 1.4(A) shows how the specific surface area increases as diameter of the particles decrease. In other words, the particle surface area is inversely proportional to the particle size[11]. A good way to think about this concept is by imagining a block of sugar versus a pile of powdered sugar with the same volume. Although they have the same proportion of sugar, the powered version has a greater surface area and, therefore, a greater ability for each particle that comprises the material to interact with outside forces. For example, when water is poured over the pile of powered sugar it can get into the space in between each particle, but when poured over the block of sugar it cannot reach the particles in the middle of the block, only the particles on the edges. This idea is demonstrated in Figure 1.4(B). The specific surface area of a spherical particle can be calculated by the following equation [12]

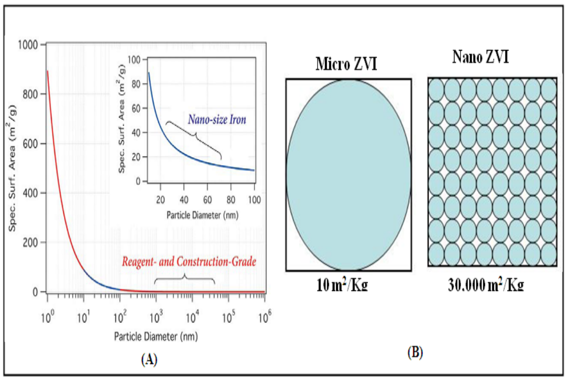


Figure 1.4 (A) Particle surface area calculated from diameter assuming spherical geometry and density 6.7 g/cm^3 (based on the average of densities for pure Fe0 and Fe$_3$O$_4$) ***(B)*** *Comparison of available surface area between micro and nano zero valent iron (ZVI)*

$$SSA = \frac{SurfaceArea}{Mass} = \frac{\pi d^2}{\rho \frac{\pi}{6} d^3} = \frac{6}{\rho d} \qquad \text{.......(1.1)}$$

2.2.1 Definitions

The terminologies very often applied in nanoscience and nanotechnologies are listed as follows:

Nanoparticles:

Although not specifically describing nanoparticles, the above-mentioned definitions imply a nanoparticle definition of particle less than 100 nm. Those particles having (one or more) dimensions of 100 nm or less and physical and chemical properties should also be to differ measurably than those of the bulk material can be called as 'nanoparticules' [13, 14].

Nanocomposites:

The composite materials, that combine one or more separate components in order to improve performance properties, for which at least one dimension of the dispersed particles is in the nanometer range.

Nanomaterials:

The development and use of nanoscale materials such as nanoparticles, nanocomposites, nanopowder, nanocrystals, etc.

Nanoscience:

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at larger scale.

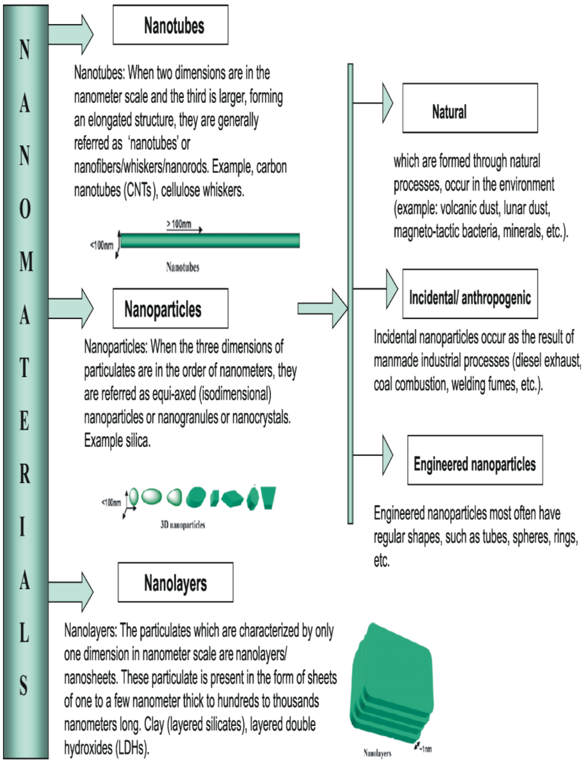
Nanoparticles as shown in Figure 1.5, are classified into three categories depending on their dimensions as follows:

- Natural,
- Incidental, and
- Engineered

There are many naturally occurring nanoparticles, such as clays, weathered minerals, organic matter, and metal oxides [15, 16].

Incidental nanoparticles are generated in a relatively uncontrolled manner and can occur as a byproduct of fuel combustion, manufacturing, agricultural practices, vaporization, weathering, and release into the environment from nanoparticle production facilities [17, 18].

Engineered nanoparticles are intentionally designed and manufactured with specific properties or compositions (e.g., shape, size, surface properties, and chemistry) and may be released into the environment through industrial or environmental applications[19].



Nanotubes: When two dimensions are in the nanometer scale and the third is larger, forming an elongated structure, they are generally referred as 'nanotubes' or nanofibers/whiskers/nanorods. Example, carbon nanotubes (CNTs), cellulose whiskers.

Nanoparticles: When the three dimensions of particulates are in the order of nanometers, they are referred as equi-axed (isodimensional) nanoparticles or nanogranules or nanocrystals. Example silica.

Nanolayers: The particulates which are characterized by only one dimension in nanometer scale are nanolayers/ nanosheets. These particulate is present in the form of sheets of one to a few nanometer thick to hundreds to thousands nanometers long. Clay (layered silicates), layered double hydroxides (LDHs).

which are formed through natural processes, occur in the environment (example: volcanic dust, lunar dust, magneto-tactic bacteria, minerals, etc.).

Incidental nanoparticles occur as the result of manmade industrial processes (diesel exhaust, coal combustion, welding fumes, etc.).

Engineered nanoparticles most often have regular shapes, such as tubes, spheres, rings, etc.

Figure 1.5: Schematic classification of nanobiomaterials

At present, Engineered Nanoparticles (ENP) (e.g. silicon dioxide, titanium dioxide, cerium oxide and iron oxides) are of major economic interest[17]. They are already widely used in pharmacy, electronic and cosmetic industry, in consumer products like sun creams, scratch resistant paints and in semiconductors [19].

2.3. Nanoremediation

Nanoremediation methods entail the application of reactive nanomaterials for transformation and detoxification of pollutants. These nanomaterials have properties that enable both chemical reduction and cataly-sis to mitigate the pollutants of concern. For nanoremediation in situ, no groundwater is pumped out for above-ground treatment, and no soil is transported to other places for treat-ment and disposal[20].

Nanomaterials have highly desired prop-erties for in situ applications. Because of their minute size and innovative surface coatings, nanoparticles may be able to pervade very small spaces in the subsurface and remain suspended in groundwater, allowing the particles to travel farther than larger, macro-sized particles and achieve wider distribution. However, in practice, current nanomaterials used for remediation do not move very far from their injection point[21].

2.4. Biopolymer based nanoadsorbents

Biopolymers are those polymers which occur in nature and have exhibited potential application in many fields such as agriculture [22, 23], hygienic products[24, 25], wastewater treatment[26,27] and drug-delivery[28]. Biopolymers are made of simple biological compounds and are produced by living organisms. They are renewable materials, generally non-toxic and biodegradable, thus combining excellent functional properties with environmental friendliness and sustainable development features [29, 30].

Thus so far, many kinds of materials have been used for preparing superabsorbents, among them the naturally available resources such as polysaccharides and inorganic clay minerals have shown particular advantages and drawn considerable attention[30]. The utilization of low cost, annually renewable and biodegradable polysaccharides for deriving superabsorbents has offered commercial and environmental superiorities[31-33]. Presently, the natural polysaccharides including starch [34, 35], cellulose[36], chitosan[37], alginate[38] and gelatin [31] have been used for deriving superabsorbents, and the resultant materials have also shown potentials as substitutes for existing petroleum-based superabsorbent materials.

Polysaccharides, stereo regular polymers of monosaccharides (sugars), are unique raw materials in that they are: very abundant natural polymers (they are referred to as biopolymers); inexpensive (low-cost polymers); widely available in many countries; renewable resources; stable and hydrophilic biopolymers; and modifiable polymers. They also have biological and chemical properties such as non-toxicity, biocompatibility, biodegradability, polyfunctionality, high chemical reactivity, chirality, chelation and adsorption capacities. The excellent adsorption behavior of polysaccharides is mainly attributed to:

- High hydrophilicity of the polymer due to hydroxyl groups of glucose units;
- Presence of a large number of functional groups (acetamido, primary amino and/or hydroxyl groups);
- High chemical reactivity of these groups;
- Flexible structure of the polymer chain.

For over 30 years, polysaccharides have attracted attention of the nanotechnology scientists. They were found to be effective colloidal stabilizers, agents for increased biocompatibility, conferring chemical functionality towards nanostructures, from carbon nanotubes, to colloidal silver and gold particles[39], quantum dots and iron oxide magnetic nanoparticles (FeONPs).

A number of studies focus their efforts on developing chemical and physical strategies for the synthesis of FeONPs with controllable size, shape, morphology and magnetic properties. These are important parameters to take into account for different FeONPs applications. However, due to their hydrophobic surfaces and large surface area to volume ratio, FeONPs tend to agglomerate in both biological medium and magnetic field, creating heterogeneous size distribution patterns. For instance, for in vivo applications agglomeration can result in rapid clearance from circulation and unexpected responses. In general, there is the need to disperse FeONPs into suitable solvents or to coat them with certain molecules and polymers in order to form homogeneous solutions called ferrofluids. A wide range of monomers, polymers and inorganic materials can be utilized for this stabilizing purpose, where the balance between steric and electrostatic repulsive forces is crucial [40].

2.4.1 Biopolymers as surface modification agents for FeONPs

The biopolymers most commonly used for coating FeONPs include agarose, alginate, carrageenan, chitosan, dextran, gum arabic, heparin, pullulan, gelatin and starch. They can be obtained from various sources, as summarised in Table 1.1 and each bring distinct properties. The surface of FeONPs can react with different functional groups, which enlarges the range of strategies for the coating of FeONPs with polysaccharides.

The coating of FeONPs can be achieved during or after synthesis, or it can be performed in-situ or by encapsulation. In general, coating leads to the creation of more hydrophilic nanostructures via end grafting, encapsulation, hyperbranching, or hydrophobic interactions[41]. Apart from enabling stabilization and improving dispersal, FeONPs are also coated with various molecules to improve biocompatibility and increase surface functionality, which opens up the possibility of creating multimodal and multifunctional FeONPs Figure 1.6 One of the crosslinking scheme of gelatin naoparticles and the incorporation of iron oxide on these nps has been depicted in Figure 1.7(a) and in Figure 1.7 (b)

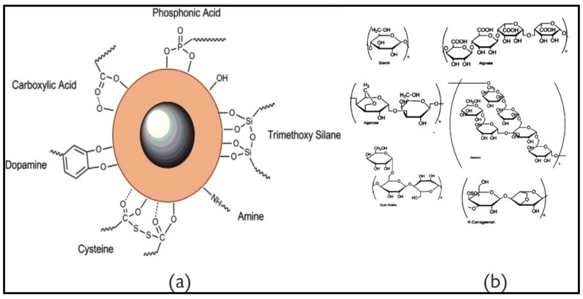


Figure 1.6 Common chemical moieties for the anchoring of polymers and functional groups at the surface of iron oxide nanoparticles [42]

Biopolymers	**Natural source**	**Charge**	**Functional groups**
Agarose	Extracted from marine red algae	Neutral	OH
Alginate	Extracted from brown algae	Negative	OH, COO^-
Carrageenans	Extracted from red seaweeds	Negative	OH, OSO_3^-
Chitosan	Extracted from shellfish or fungi cell wall	Positive	OH, NH_3^+
Dextran	Produced by lactic acid bacteria	Neutral	OH
Gum Arabic	Extracted from exudates of Acacia trees	Negative	OH, COO^- Peptide moieties
Heparin	Extracted from animal tissues	Negative	OH, OSO_3^-
Pullulan	Exopolysaccharide aerobically produced by fungus	Neutral	OH
Starch	Produced by green plants	Neutral	OH
Gelatin	Extracted from animal bones	Neutral	COO^-, NH_3^+

Table1.1 Properties of biopolymers commonly used for FeONPs coating or encapsulation.

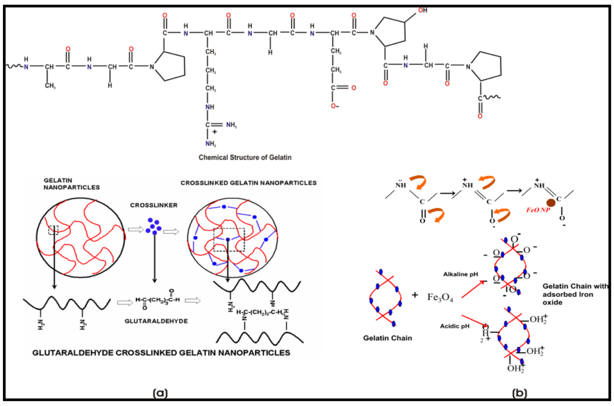


Figure 1.7 reaction scheme of depicting the scheme of crosslinking in gelatin nanoparticles (a) and incorporation of iron oxide onto the gelatin nanoparticles.

III. Biotechnological and Bio-Engineering Applications

Iron oxide NPs alone or associated with various polymers have been explored for biotechnological and bioengineering application, and the fields in which biopolymer -based FeONPs are currently being used are summarised in Table 1.2 and Figure 1.8.

3.1. Bioseparation processes.

MNPs are promising on an industrial scale in aqueous environments, as they can be made cheaply and easily, and coated with different polymeric materials as to increase colloidal stability, morphology and functionality. The small size of the stabilized particles results in dispersions having a large surface area to unit volume ratio. This makes the particles highly attractive for use in adsorptive separations. A magnetic separation process, sometimes referred to as magnetic fishing, is mostly widespread as a laboratory and small scale procedure. MNPs coated with different functional groups (either commercially available or in-house prepared) are incubated with a sample, and adsorption of the product of interest at the MNP surface occurs; then using a small magnet or magnetic rack, the MNPs are attracted to the magnet and the supernatant is easily recovered. Finally, the product of interest is eluted from the FeONPs by conventional elution conditions. A more complex, scalable and automated process, includes the use of high gradient magnetic separation (HGMS) systems at pilot-scale – and this is currently an active area development.

Polymer	**Ligand**	**Application**
Agarose	Thiophilic Ni-NTA	Antibody Purification His-tagged caspase purification
Alginate	- -	Copper adsorption Arsenic adsorption from water
Carrageenan	Soy trypsin inhibitor	Trypsin purification
Chitosan	PEG and PEI - - Glucose Oxidase Hemoglobin DNA - Yeast cells	Magnetofection Protein separation Protein separation and biocatalysis Antibody purification Hydrogel for bioseparation Biosensor model Detection of pyrethroids Copper adsorption from water
Dextran Agarose	- Antibody Concavalin A Antibody	Lysosomes separation Separation of proteins or cells Separation of E.coli O157:H7 Assessment of antimicrobial susceptibility Detection of viral particles Protein separation Lectins separation
Gum Arabic	Biomimetic Ligands - Glucose	Antibody purification Copper adsorption Concanavalin A adsorption

Table 1.2 Biotechnological applications of FeONPs coated with biopolymers

3.2. Biosensing

A biosensor is essentially a device capable of converting a biological event into a physico-chemical signal. FeONPs are interesting platforms for these purposes as their surface can be easily modified with various receptors, and they can serve as ferromagnetic labels on their own. The development of magnetic immunoassays and miniaturized sensitive sensors based on FeONPs is an area of intensive research [43-45].

3.3. Biocatalysis and bioremediation

The development of the industry and growth of population led to the intensive production of residues and pollution of water and soils. This derived on the need to clean industrial water streams before their introduction in the environment, to decontaminate soils due to the excess of herbicides, hazardous organic compounds and heavy metals or fuels. In other situations, biopolymers also serve as the adsorbents for various toxins. Gum arabic coated MNPs were utilized as nanoadsorbent for copper ions. Although naked MNPs can adsorb copper ions (due to the complexation with hydroxyl groups in the surface of the MNP), the adsorption capacity was higher for gum Arabic-modified MNPs (the complexation of copper ions is made through amino groups from the polysaccharide). Arsenic is another important contaminant in water and diverse technologies attempt to eliminate this toxin. Recently, the use of adsorptive systems attracted particular interest for arsenic removal. Alginate FeONPs were explored as adsorbents for arsenic removal from water, showing that the combination of the biopolymer with the FeONPs yielded the strongest adsorption, as opposed to naked alginate beads or naked FeONPs.

3.4. Magnetofection

Magnetofection is a process where DNA associated with MNPs is transfected into cells using an external magnetic field. In general, nucleic acids associate with cationic MNPs. Polyethylenimine (PEI) alone forms a complex with DNA and helps the DNA transfection by neutralizing the negative charge. The complex enters into cells by endocytosis but is toxic to cells. MNPs coated with a complex of chitosan, polyethylene glycol (PEG) and polyethylenimine (PEI) were explored as a vector for DNA delivery [46, 47].

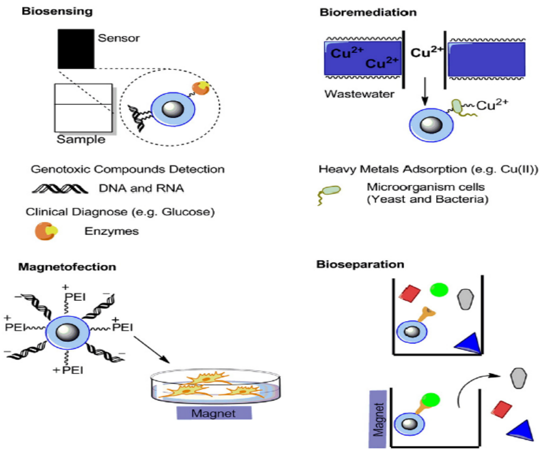


Figure 1.8 : Biotechnological applications of pollysaccharide coated magnetic FeoNPs

IV. CONCLUSIONS AND FUTURE PERSPECTIVES

In this review, an attempt has been made to focus on the recent developments related to the detoxification of water and wastewater by iron oxide based bioadsorbents. The use of biopolymers as adsorbents for removing various pollutants from water and wastewater presents many attractive features especially their contribution in the waste disposal, therefore contributing to environmental protection. Although the amount of available literature data on the use of low-cost adsorbents in water and wastewater treatment is increasing at a tremendous pace, there are still several gaps which need to be filled. Some of the important issues can be summarized below:

1. Selection and identification of an appropriate bioadsorbent is one of the key issues to achieve the maximum removal/adsorption of specific type of pollutant depending upon the adsorbent–adsorbate characteristics.

2. The conditions for the production of biopolymer based adsorbents after surface modification for higher uptake of pollutants need to be optimized.

3. Cost factor should not be ignored. Low production cost with higher removal efficiency of adsorbents would make the process economical and efficient.

4. Mechanistic studies need to be performed in detail to propose a correct binding mechanism of aquatic pollutants with biopolymer adsorbents.

5. Regeneration studies need to be performed in detail with the pollutants-laden adsorbent to recover the adsorbate as well as adsorbent. It will enhance the economic feasibility of the process.

6. The potential of iron oxide based nanoadsorbents under multi-component pollutants needs to be assessed. This would make a significant impact on the potential commercial application of adsorbents to industrial systems.

7. There is scarce data available for the competitive adsorption of pollutants (metal ions adsorption in presence of phenols, dyes and other contaminants and vice-versa). Therefore, more research should be conducted in this direction.

8. It is further suggested that the research should not limit to only lab scale batch studies, but pilot-plant studies should also be conducted utilizing biopolymer adsorbents to check their feasibility on commercial scale.

9. The effectiveness of the treatment depends not only on the properties of the adsorbent and adsorbate, but also on various environmental conditions and variables used for the adsorption process, e.g. pH, ionic strength, temperature, existence of competing organic or inorganic compounds in solution, initial adsorbate/adsorbent concentration, contact time and speed of rotation, particle size of adsorbent, etc. These parameters should also be taken into account while examining the potential of adsorbents.

10. The development in the field of adsorption process using biopolymer based adsorbents essentially requires further investigation of testing these materials with real industrial effluents.

11. Last but not the least, environmentally safe disposal of pollutants-laden adsorbents is another important topic of concern which should not be overlooked. If it is possible to develop such adsorbents having all the above-mentioned characteristics, then these adsorbents may offer significant advantages over currently available expensive commercially activated carbons and, in addition contribute to an overall waste minimization strategy.

RECERENCES:

[1] T. Pradeep and Anshup, (2009) *Thin Solid Films.,* 517 6441–6478,

[2] Helmer, R., and Hespanhol I., (1997) Water Pollution Control – A Guide to the Use of Water Quality Management Principles. E & FN Spon, London, Great Britain.

[3] US Environmental Protection Agency, National Primary Drinking Water Regulations and Contaminant Candidate List, cited 18 Dec 2008, available from: http:// www.epa.gov/ogwdw/contaminants/index.html http://www.epa.gov/ogwdw/ccl/ccl2.html.

[4] Jonathon Brame, Qilin Li and Pedro J.J. Alvarez (2011), *Trends in Food Science & Technology* 1-7

[5] U.S. EPA. 2007a. Office of Solid

Waste and Emergency Response. Treatment Technologies for Site Cleanup: Annual Status Report (Twelfth Edition). Report number: EPA-542-R-07- 012.

[6] Zhang, W. X. (2003) *J. Nanopart. Res.,* 5: 323–332.

[7] Davies, C.J. (2009) Oversight of next generation nanotechnology. Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars.

[8] Klaine, S. J, Alvarez, P.J, Batley, G.E, Fernandes, T.F., Hand, R.D., Lyon, D.Y., Mahendra, S., McLaughlin, M.J. Lead, J. R. (2008) *Environ. Toxicol. Chem.,* 27:1825–51.

[9] ISO. International Organization for Standardization. Nanotechnologies – Terminology and definitions for nano -objects – Nanoparticle, nanofibre and nanoplate. ISO/TS 27687 (2008-08-15).

[10] Tratnyek, P.G., Johnson, R.L. (2006) *Nanotoday.,* 1:44–48.

[11] CSL. 2009. Colloidal Science Laboratory, Inc. Determining the properties of metal colloids.

[12] Mace, C., Desrocher, S., Gheorghiu, F., Kane, A., Pupeza, M., Cernik, M., Kvapil, P.,Venkatakrishnan, R., Zhang, W.X. (2006) *Remediation J.,* 6: 23–33.

[13] Whatmore, R.W. (2006) *Occup. Med.,* 56: 295–299.

[14] ISO (2004). Occupational ultrafine aerosol exposure characterization, assessment. Draft technical report number 6. ISO/TC146/SC2WG1 Particle size selective sampling and analysis (workplace air quality); 2004.

[15] Watlington K. (2005) Emerging Nanotechnologies for Site Remediation and Wastewater Treatment.

[16] NNI. 2009. National Nanotechnology Initiative. Leading to a Revolution in Technology and Industry.

[17] DHHS. 2009. Department of Health and Human Services, Centers for Disease Control and Prevention and National Institute for Occupational Safety and Health. Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns Associated with Engineered Nanomaterials. Publication No. 2009-125.

[18] Nowack,B., Bucheli, T.D. (2007) *Environ. Pollut.,* 150: 5–22

[19] Colvin, V.L. (2003) *Nature Biotechnol.,* 10 :1166.

[20] Otto M, Floyd M, and Bajpai S. (2008), *Remediation* 19(1), 99–108,

[21] Tratnyek PG, and Johnson RL. (2006), *Nanotoday* 1(2), 44–48,

[22] Chu, M., Zhu, S. Q., Li, H. M., Huang, Z. B., Li, S. Q. (2006) *J. Appl. Polym. Sci.,* 102: 5137–5143.

[23] Puoci, F., Iemma, F., Spizzirri, U. G., Cirillo, G., Curcio, M., Picci, N. (2008) *Am. J. Agric. Biol. Sci.,*3: 299 –314.

[24] Kamat, M., Malkani, R. (2003) *Indian J. Pediatr.,* 70: 879–881.

[25] Kosemund, K., Schlatter, H., Ochsenhirt, J. L., Krause, E.L., Marsman, D.S., Erasala, G. N. (2009) *Regul. Toxicol. Pharmacol.,* 53: 81–89.

[26] Kasgoz, H., Durmus, A. Z., Kasgoz, A. (2008) *Polym. Adv. Technol.,* 19: 213–220.

[27] Wang, Y. Q., Zhang, H. F., Wu, Y. P., Yang, J., Zhang, L. Q. (2005) *Eur. Polym. J.,* 41: 2776–2783.

[28] Sadeghi, M., Hosseinzadeh, H. J. (2008). *J. Bioact. Compat. Polym.,* 23: 381–404.

[29] Sundar S, Kundu J, and Kundu SC. Biopolymeric nanoparticles, *Sci Technol Adv Mater*;11:014104 (13 pp), (2010)

[30] Ray, S. S., Bousmina, M. (2005) *Prog. Mater. Sci.*, 50: 962–1079.

[31] Pourjavadi, A., Hosseinzadeh, H., Sadeghi, M. (2007b) *J.Compos. Mater.*, 41: 2057–2069.

[32] Yoshimura, T., Uchikoshi, I., Yoshiura, Y., Fujioka, R.(2005) *Carbohydr. Polym.,* 61: 322–326.

[33] Zhang, J. P., Wang, Q., Wang, A. Q. (2007) *Carbohydr. Polym.,* 68: 367–374.

[34] Lanthong, P., Nuisin, R., Kiatkamjornwong, S. (2006). *Carbohydr. Polym.,*66: 229–245.

[35] Li, A., Zhang, J. P., & Wang, A. Q. (2007) *Bioresour. Technol.*, 98: 327–332.

[36] Suo, A. L., Qian, J. M., Yao, Y., Zhang, W. G. (2007) *J. Appl. Polym. Sci.,*103: 1382–1388.

[37] Chen, Y., Liu, Y. F., Tan, H. M., Jiang, J. X. (2009) *Carbohydr. Polym.,* 75: 287–292.

[38] Hua, S. B., Wang, A. Q. (2009) *Carbohydr. Polym.,* 75:79–84.

[39] Talaro KP, Talaro A. Foundations in microbiology. Blacklick, Ohio, U.S.A.: McGraw-Hill College; 2002. ed 4th.

[40] Balantrapu K, and Goia DV. (2009), *J Mater Res*., 24:2828–36,

[41] Laurent S, Forge D, Port M, Roch A, Robic C, Vander Elst L, et al. (2008) *Chem Rev.*,108, 2064–110.

[42] Fang C, and Zhang M. (2009) *J Mater Chem*.,19, 6258–66

[43] [43]. Boyer C, Whittaker MR, Bulmus V, Liu J, Davis TP. (2010) NPG Asia Mater.,2, 23–30,

[44] A.M.G.C. Dias, A. Hussain, A.S. Marcos, A.C.A. (2011) *Roque Biotechnology* Advances 29 142–155,

[45] Qiao R, Yang C, Gao M (2009) *J Mater Chem*;19:6274–93.

[46] Peng Q, Liu Y, Zeng G, Xu W, Yang C, Zhang J. (2010) *J Hazard Mater*; 177: 676–82.

[47] Rinaudo M. (2008) *Polym Int*;57:397–430.

* * * * *