Chapter - 4
Applications and Implications of Environmental Nanotechnology

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Abstract

Environmental nanotechnology is considered to play an important role in the shaping and effective solutions to a huge range of environmental science and engineering. Environmental nanotechnology applications address the advancement solutions to the existing environmental problems. Rapid expansion of nanotechnology has gained a great interest in the applications of nonmaterial in systems improvement as well as enhances efficiencies of monitoring devices, renewable energy production and remediation of environmental pollution. This review article provides comprehensive information regarding the role of nanotechnology on the ongoing research on environmental remediation and its implications caused by nanotechnology. The applications of nanotechnology are reviewed and then the implications to the environment. Various environmental remediation using different types of nanostructures materials from three phases of environment are discussed. In parallel, the implications of nanotechnology on environment, such as air, water, soil contamination arising from manufacturing processes and increased toxicological pollution on the environment due to the uncertain shape, size, and chemical compositions of some of the nonmaterial's. Nanoparticles have higher surface areas than the bulk materials which can cause more damage to the environment compared to the bulk particles. Although nanotechnology risks are being explored fairly early in their development compared to other technologies, thus environmental exposure is still happening without due consideration for their potential risks.

Keywords: Environment, environmental nanotechnology, nonmaterial, nanotechnology, remediation.

1. Introduction

Nanotechnology as a field has emerged in 1980s through convergence of K.E. Drexler's theoretical and public work has now gained a worldwide attention among both the scientific and public community [1]. Nanotechnology is the manipulation of matter at a molecular and atomic scale. It means artificially combining atoms and molecules to create particles and structures with functions different from the same material at a larger scale (also called bulk material, or material in the bulk form) [2]. Nanomaterials are the drivers of the nanotechnology revolution. Thus, a key bottleneck to the applications of nanotechnology to water purification will be the availability of suppliers that can provide large quantities of nanomaterials at economically viable prices. Nanoscience and nanotechnology are concerned with the understanding and rational manipulation of materials at the atomic and molecular levels, generally with structures of less than 100 nm in size. Scientifically, nanoscience is defined as the study of phenomena and the manipulation of materials at the atomic, molecular, and macromolecular scales, where the properties differ from those at a larger scale and have unique novel functional applications [3].

Applications of nanotechnology have been emphasized on the characterization, fabrication, and manipulation of nanostructures or nanomaterials [4]. Early application of nanotechnology is remediation using nanoscale iron particles. Zero-valent iron nanoparticles are deployed in-situ to remediate soil and water contaminated with chlorinated compounds and heavy metals. The iron nanoparticles disperse throughout the body of water and decompose the organic solvent in place. This method can be more effective and cost significantly less than treatment methods that require the water to be pumped out of the ground. Among the many applications of nanotechnology that have environmental implications, remediation of contaminated groundwater using nanoparticles containing zero-valent iron is one of the most prominent examples of a rapidly emerging technology with considerable potential benefits. There are, however, many uncertainties regarding the fundamental features of this technology, which have made it difficult to engineer applications for optimal performance or to assess the risk to human or ecological [5].

The ecological implications of nanotechnology are the possible effects that the use of Nano technological materials and devices will have on the environment [6]. As nanotechnology is an emerging field, there is debate regarding to what extent industrial and commercial use of nanomaterials will affect organisms and ecosystems. In free form nanoparticles can be released in the air or water during production (or production accidents) or as waste by-product of production, and ultimately accumulate in the soil, water or plant life [7]. Environmental assessment is justified as nanoparticles present novel (new) environmental impacts. Scrinis raises concerns about Nano-pollution, and argues that it is not currently possible to “precisely predict or control the ecological impacts of the release of these Nano-products into the environment.” Ecotoxicological impacts of nanoparticles and the potential for bioaccumulation in plants and microorganisms remain under-researched. The capacity for nanoparticles to function as a transport mechanism also raises concern about the transport of heavy metals and other environmental contaminants. Not enough data exists to know for sure if nanoparticles could have undesirable effects on the environment [8].

2. Classification and Properties

2.1 Classification of nanomaterials

All conventional materials like metals, semiconductors, glass, ceramic or polymers can in principle be obtained with a nanoscale dimension. The spectrum of nanomaterials ranges from inorganic or organic, crystalline or amorphous particles, which can be found as single particles, aggregates, powders or dispersed in a matrix, over colloids, suspensions and emulsions, Nano layers and films, up to the class of fullerenes and their derivates. Also supramolecular structures such as dendrimers, micelles or liposomes belong to the field of nanomaterials [9].

Table 1: classification of nanomaterials with regard to different parameters

Classification	Examples
Dimension ▪ 1 dimension ▪ 2 dimension ▪ 3 dimension	Films, coatings, multilayer, etc. Tubes, fibers, wires, platelets, etc. Particles, quantum dots, hallow spheres, etc.
Phase Composition ▪ Single-phase solid ▪ Multi-phase solid ▪ Multi-phase system	Crystalline, amorphous, particles and layers, etc. Matrix composites, coated particles, etc. Colloid, aerogels, ferrofluids, etc.
Manufacturing Process ▪ Gas phase reaction ▪ Liquid phase reaction ▪ Mechanical procedures	Flame synthesis, condensation, CVD, etc. Sol-gel, precipitation, hydrothermal processing, etc. Ball milling, plastic deformation, etc.

2.1.1 Nanoparticles

Nanoparticles are constituted of several tens or hundreds of atoms or molecules and can have a variety of sizes and morphologies (amorphous, crystalline, spherical, needles, etc.). Some kind of nanoparticles are already available commercially in the form of dry powders or liquid dispersions. The latter is obtained by combining nanoparticles with an aqueous or organic liquid to form a suspension or paste. It may be necessary to use chemical additives (surfactants, dispersants) to obtain a uniform and stable dispersion of particles. With further processing steps, nanostructured powders and dispersions can be used to fabricate coatings, components or devices that may or may not retain the nanostructure of the particulate raw materials. Industrial scale production of some types of nanoparticulate materials like carbon black, polymer dispersions or micronised drugs has been established for a long time.

Another commercially important class of nanoparticulate materials are metal oxide nanopowders, such as silica (SiO_2), titania (TiO_2), alumina (Al_2O_3) or iron oxide (Fe_2O_4, Fe_2O_3). But also other nanoparticulate substances like compound semiconductors (e.g. cadmium telluride, CdTe, or gallium arsenide, GaAs) metals (especially precious metals such as Ag, Au) and alloys are finding increasing product application. Besides that, the range of macromolecular chemistry with molecule sizes in the range of up to a few tens of nanometers is often referred to as nanotechnology. Molecules of special interest that fall within the range of nanotechnology are fullerenes or dendrimers (tree-like molecules with defined cavities), which may find application for example as drug carriers in medicine [9].

2.1.2 Nanowires and Tubes

Linear nanostructures such as nanowires, nanotubes or nanorods can be generated from different material classes e.g. metals, semiconductors or carbon by means of several production techniques. As one of the most promising linear nanostructures carbon nanotubes can be mentioned, which can occur in a variety of modifications (e.g. single or multiwalled, filled or surface modified). Carbon nanotubes are expected to find a broad field of application in nanoelectronics (logics, data storage or wiring, as well as cold electron sources for flat panel displays and microwave amplifiers) and also as fillers for nanocomposites for materials with special properties. At present carbon nanotubes can be produced by CVD methods on a several tons per year scale and the gram quantities are already available commercially[9].

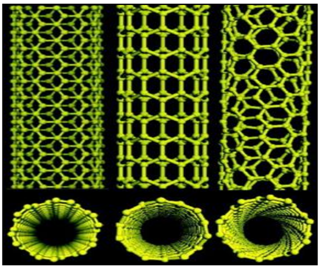

Fig 1: Carbon nanotube

2.1.3 Nanolayers

Nanolayers are one of the most important topic within the range of nanotechnology. Through nanoscale engineering of surfaces and layers a vast range of functionalities and new physical effects (e.g. magnetoelectronic or optical) can be achieved. Furthermore a nanoscale design of surfaces and layers is often necessary to optimise the interfaces between different material classes (e.g. compound semiconductors on silicon wafers) and to obtain the desired special properties [9].

Table 2: Tunable properties by nanoscale surface design and their application potentials

Surface Properties	Application Examples
Mechanical properties (e.g. tribology, hardness, scratchresistance)	Wear protection of machinery and equipment, mechanical protection of soft materials (polymers, wood, textiles, etc.)
Wetting properties (e.g. antiadhesive, hydrophobic, hydrophilic)	Antigraffiti, antifouling, Lotus-effect, self-cleaning surface for textiles and ceramics, etc.
Thermal and chemical properties (e.g. heat resistance and insulation, corrosion resistance)	Corrosion protection for machinery and equipment, heat resistance for turbines and engines, thermal insulation equipment and building materials, etc.
Biological properties (biocompatibility, antiinfective)	Biocompatible implants, abacterial medical tools and wound dressings, etc.
Electronical and magnetic properties (e.g. magnetoresistance, dielectric)	Ultrathin dielectrics for field-effect transistors, magnetoresistive sensors and data memory, etc.
Optical properties (e.g. antireflection, photo- and electrochromatic)	Photo- and electrochromic windows, antireflective screens and solar cells, etc.

2.1.4 Nanopores

Materials with defined pore-sizes in the nanometer range are of special interest for a broad range of industrial applications because of their outstanding properties with regard to thermal insulation, controllable material separation and release and their applicability as templates or fillers for chemistry and catalysis. One example of nanoporous material is aerogel, which is produced by sol-gel chemistry. A broad range of potential applications of these materials include catalysis, thermal insulation, electrode materials, environmental filters and membranes as well as controlled release drug carriers [9].

2.2 Properties of Nanomaterials

The physical and chemical properties of nanostructured materials (such as optical absorption and fluorescence, melting point, catalytic activity, magnetism, electric and thermal conductivity, etc.) typically differ significantly from the corresponding coarser bulk material. These special properties of nanomaterials are mainly due to quantum size confinement in nanoclusters and an extremely large surface to volume ratio relative to bulk materials and therefore a high percentage of atoms/molecules lying at reactive boundary surfaces. For example in a particle with 10 nm diameter only approx. 20 per cent of all atoms are forming the surface, whereas in a particle of 1 nm diameter this figure can reach more than 90 per cent. The increase in the surface to volume ratio results in the increase of the paricle surface energy, which leads to e.g. a decreasing melting point or an increased sintering activity. It has been stated that large specific surface area of particles may significantly raise the level of otherwise kinetically or thermodynamically unfavourable reactions. Even gold (Au), which is a very stable material, becomes reactive when the particle size is small enough. With precise control of the size of the particles their characteristics can be adjusted in certain borders. Though it is usually difficult to maintain these desired characteristics beyond the different manufacturing processes to the final product, because loose nano-powders tend to grow to larger particles and/or firmly connected agglomerates already at room temperature and thus loosing there nano-specific characterisitcs. Therefore it is necessary to select or develop suitable production processes and further refining/treatment processes (e.g. coating of nanoparticles) to prevent or attentuate agglomeration and grain growth during generation, processing and use of nanomaterials [9].

Table 2: Adjustable properties of nanomaterials

Properties	Examples
Catalytic	Better catalytic efficiency through high surface-to-volume ratio
Electrical	Increase electrical conductivity in ceramics and nanocomposits, increase electric resistance in metals
Magnetic	Increase magnetic coercivity up to a critical grain size superparamagnetic behaviour
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramic
Optical	Spectral shift of optical abortion and fluorescence properties, increase quantum efficiency of semiconductor crystals
Sterical	Increased selectivity, hallow spheres for specific drug transformation and controlled release
Biological	Increased permeability through biological barriers (membranes, blood-brain barrier, etc.), improved biocompatibility

2.3 Characteristics of Nanoparticulate Materials

In this report we focus on nanoparticulate materials which have structure sizes smaller than 100 nm in at least two dimensions. These nanoparticulate materials can have various shapes and structures such as spherical, needle-like, tubes, platelets, etc. Chemical composition is another important parameter for the characterisation of nanoparticulate materials, which comprise nearly all substance, classes e.g. metals/metal oxides, polymers, compounds as well as biomolecules. Under ambient conditions nanoparticles tend to stick together and form aggregates and agglomerates. These aggregates/agglomerates have various forms, from dendritic structure to chain or spherical structures with sizes normally in the micrometer range. The properties of nanoparticles can be significantly altered by surface modification. For example, nanoparticles are often stabilised with coatings or molecule adducts to prevent agglomeration. For the characterisation of nanoparticulate materials it is further important in which medium the nanoparticles are dispersed e.g. in gaseous, liquid or solid phase [9].

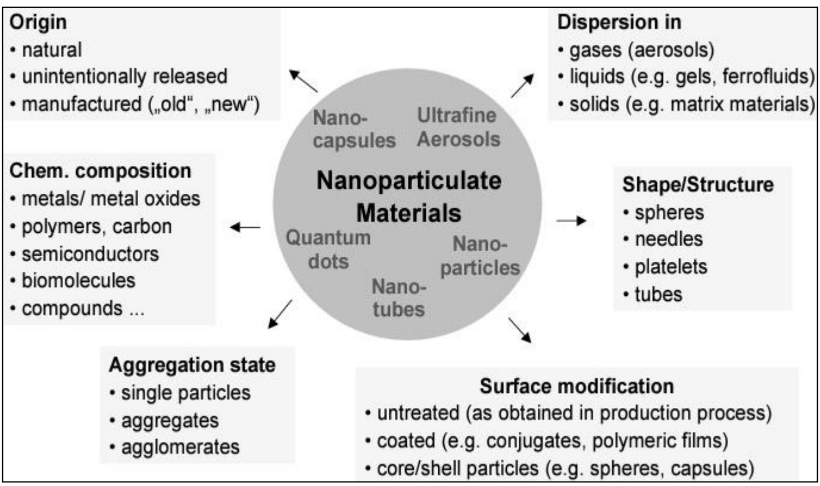

Fig: Characteration parameters of nanoparticulate materials (source; Luther, 2004).

3. Environmental Applications of Nanotechnology

3.1 Air pollution Remediation

Current research in nanoscale level develops novel, highly effective, low cost efficient methodologies for pollution remediation. Pollution of air is remediating using nanotechnology in different ways. One is through the use of nano-catalysts with increased surface area for gaseous reactions. Catalysts work by speeding up chemical reactions that transform harmful vapours from cars and industrial plants into harmless gases [10]. Silver nanoclusters as catalysts can significantly reduce the polluting byproducts generated in the process used to manufacture propylene oxide. Propylene oxide is used to produce common materials such as plastics, paint, detergents and brake fluid [11]. Catalysts currently in use include a nanofiber catalyst made of manganese oxide that removes volatile organic compounds from industrial smokestacks [10]. Another different approach uses nanostructured membranes that have pores small enough to separate methane or carbon dioxide from exhaust [10]. Carbon Nano Tubes (CNT) can trap gases up to hundred times faster than other methods, allowing integration into large scale industrial plants and power stations. This new technology both processes and separates large volumes of gas effectively, unlike conventional membranes that can only do one or the other effectively. In 2006, it was found a way to collect the soot filtered out of diesel fuel emissions and recycle it into manufacturing material for CNT [12]. The diesel soot is used to synthesize the single walled CNT filter through laser vaporization so that essentially, the filtered waste becomes the filter. Similarly, to reduce air pollution nanosized catalyst and nanostructure membrane are effectively used for air remediation.

3.2 Soil Contamination Remediation

Soil contaminations are remediated using nanotechnology. Zero valent iron nanoparticles (nZVI) were considered promising for the remediation of contaminated soils targeting a wide range of contaminants, and especially Polychlorinated biphenyls (PCB). Technologies include such as incineration, landfill disposal, thermal desorption, solvent extraction and soil washing. Conventional physical/chemical remedial technologies such as incineration and landfill disposal have been frequently used, but these solutions are disruptive and unsustainable [13]. However, critical issues related to their limited mobility remain unsolved. A direct current can be used to enhancing the nanoparticles transport, based on the same principles of electro kinetic remediation (EK). Integrating both technologies, the role of the direct electric current would be to get nZVI into the soil for in-situ transformation and subsequent destruction of the contaminants, instead of aiming at the contaminants transport for removal [14]. The iron nano-particles were also used to remediate Malathion contaminated soil in the concentration range of 1-10 $\mu \cdot g^{-1}$. The zero valent iron nano-particles were prepared by reducing ferric chloride solution with sodium borohydride for remediation of the soil. The optimized quantity of iron nano particles was found to be 0.1 $g \cdot kg^{-1}$ of soil contaminated with 10 $g \cdot kg^{-1}$ of Malathion. Malathion was determined in the soil after leaching to water at pH 8.2 and followed by its oxidation with slight excess of N-bromosuccinimide (NBS). The unconsumed NBS was estimated by measuring the decrease in the color intensity of rhodamine B. Degradation product formed during the oxidation of Malathion by zero valent iron was monitored by the Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR) [15]. Malathion {Di-ethyl 2 [(dimethoxyphosphorothioyl) sulfanyl] butanedio-ate}, commonly referred to as organophosphorous pesti-cides (OPPs) is used as insecticides for control of insects on fruits and vegetables, organic phosphate pesticides are of great environmental concern primarily because they are toxic to mammals and birds [16].

3.3 Water Contamination Remediation

The use of nanoparticles for decontamination of waters began in the 1990s; it was considered a new technology and its development is still in progress. The harmful pollutants in water can be converted into harmless chemicals through chemical reactions. Trichloroethene, a dangerous pollutant commonly found in industrial wastewater, can be catalyzed and treated by nanoparticles. Gillham was the first researcher to present the idea of using zero valence iron in permeable reactive barriers (PRB), based on his experience with the use of zero valence iron on decontamination of waters containing contaminants of the halogenated group [17, 18]. The use of zero-valent iron (ZVI or Fe^0) for in situ remedial treatment has been expanded to include all different kinds of contaminants [19]. Studies have shown that these“materials should be highly suitable as hydrodehalogenation and reduction catalysts for the remediation of various organic and inorganic groundwater contaminants [20]. Zero-valent iron removes aqueous contaminants by reductive dechlorination, in the case of chlorinated solvents, or by reducing to an insoluble from, in the case of aqueous metal ions. Iron also undergoes “Redox” reactions with dissolved oxygen and water:

$$2Fe^{o}_{(s)} + O_{2(g)} + H_2O \rightarrow 2Fe^{2+}_{(aq)} + 4OH^{-}_{(aq)}$$

$$Fe^{o}_{(s)} + 2H_2O \rightarrow 2Fe^{2+}_{(aq)} + H_{2\,(g)} + 2OH^{-}_{(aq)}$$

Supported zero-valent iron nanoparticles with 10-30 nm in diameter were also prepared [21]. These nanoparticles were used for separation and immobilization of Cr (VI) and Pb (II) from aqueous solution by reduction of chromium to Cr (III) and Pb to Pb (0) [19]. The reaction of metallic iron Fe^0 to the Fe^{2+} dissolved in water has a standard potential E^0 of - 440 mV, indicating that the Fe^0 has great capacity for reducing contaminants. The most common processes of organic contaminants degradation by Fe^0 are hydrogenolysis and dehalogenation [22, 23].

Nanotechnology eases the water cleansing process because inserting nanoparticles into underground water sources is cheaper and more efficient than pumping water for treatment [20]. The deionization method of using nano-sized fibers as an electrode is not only cheaper, but also more energy efficient [24]. Iron nanoparticles can be effective in cleaning up organic solvents that are polluting groundwater. The iron nanoparticles disperse throughout the body of water and decompose the organic solvent in place. Traditional water filtering systems use semi-permeable membranes for electrodialysis or reverse osmosis. Decreasing the pore size of the membrane to the nanometer range would increase the selectivity of the molecules allowed to pass through. Membranes that can even filter out viruses are now available [25]. Nanotechnology is also widely used in separation, purification, and decontamination processes are ion exchange resins, which are organic polymer substrate with nano-sized pores on the surface where ions are trapped and exchanged for other ions [26]. Ion exchange resins are mostly used for water softening and water purification.

4. Ecological Implications of Nanotechnology

There have been serious implications which are coming into light in the recent years within different environmental compartments, namely air, water and soil. The implications of nanotechnology on environment, such as air, water, soil contamination arising from manufacturing processes and increased toxicological pollution on the environment due to the uncertain shape, size, and chemical compositions of some of the nanomaterials. Nanoparticles have higher surface areas than the bulk materials which can cause more damage to the environment compared to the bulk particles. The understanding of the environmental effects and risks associated with nanotechnology is very limited and inconsistent. The potential environmental harm through nanotechnology can be summarized as follows: High energy requirements for synthesizing nanoparticles causing high energy demand, Dissemination of toxic, persistent nanosubstances originating environmental harm, Lower recovery and recycling rate and Environmental implications of other life cycle stages also not clear and Lack of trained engineers and workers causing further concerns [27]. Even although nanotechnology risks are being explored fairly early in their development compared to other technologies, thus environmental exposure is still happening without due consideration for their potential risks.

Even as that only time will provide answers to many key environmental questions, including the following: What are the potential environmental concerns associated with this new technology?, Can industry and society expect toxic/hazardous material to be released into the environment during either the manufacture or use of nanoproducts?, Could nanoapplications lead to environmental degradation, particularly from bioaccumulation of nanoproducts in living tissue? and What impact will regulations have on this new technology? [28]. With regards to these questions, the environmental health and hazard risks associated with both nanoparticles and the applications of nanotechnology for commercial and industrial uses are not fully known [20, 30, 31]. Some early studies suggest that nanoparticles might serve as environmental poisons that accumulate in organs. Although these risks may prove to be either minor, avoidable, or both, the engineer and scientist are duty bound to determine if there are in fact any health, safety, and environmental impacts associated with nanotechnology [30].

5. Conclusion

This review study provided comprehensive information regarding the role of nanotechnology on the ongoing research on environmental remediation and its implications caused by nanotechnology in three phases of environment such as; air, soils and water. Nanotechnology addresses some of the greatest environmental challenges of the 21st century by providing routes to remediate environmental contamination, nanotechnology continue to develop, be a benefit to society and improve the environment in various ways. Nanoscale materials makes the products better in terms of functionality, weight savings, less energy consumption and remediate environmental contamination. Shortcomings always exist when new unproven technology is released. Although nanotechnology risks are being explored fairly early in their development compared to other technologies, thus environmental exposure is still happening without due consideration for their potential risks.

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