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Review Article

APPLICATION OF NANOTECHNOLOGY IN MONITORING AND CONTROL OF POLLUTION

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ABSTRACT

The purpose of this article is to explain the scope of pollution control through Nanotechnology, including the need for the responsible attainment of the pollution control benefits that can result from nanotechnology. Nanotechnology can monitor and control pollution by using products that are less toxic, less polluting, and wear-resistant; processes that are more efficient and waste-reducing; processes or products that use less energy and fewer raw materials because of greater efficiency.

Keywords: Pollution control, Nanomaterials, Nanocomposites, Nanofiltration

INTRODUCTION

Pollution is the introduction of contaminants into an environment that causes instability, disorder, harm or discomfort to the ecosystem, i.e., physical systems or living organisms. Pollution can take the form of chemical substances or energy, such as noise, heat or light energy. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring. A pollutant is a waste material that pollutes air, water or soil. Three factors determine the severity of a pollutant: its chemical nature, the concentration and the persistence [1]. To protect the environment from the adverse effects of pollution, many nations worldwide have enacted legislation to regulate various types of pollution as well as to mitigate the adverse effects of pollution [2].

Nanotechnology, shortened to "nanotech", is the study of the control of matter on an atomic and molecular scale [3]. Generally, nanotechnology deals with structures of the size 100 nanometers or smaller and involves developing materials or devices within that size [4]. Nanotechnology is very diverse, ranging from novel extensions of conventional device physics, to completely new approaches based upon molecular self-assembly, to developing new materials with dimensions on the nanoscale, even to speculation on whether we can directly control matter on the atomic scale. The environmental implications of nanotechnology are the possible effects that the use of nanotechnological materials and devices will have on the environment [5]. As nanotechnology is an emerging field, there is great debate regarding what extent industrial and commercial use of nanomaterials will affect organisms and ecosystems [6].

Pollution control

Pollution control is reducing or eliminating waste at the source by modifying production process, promoting the use of non-toxic or less-toxic substances, implementing conservation techniques, and re-using materials rather than putting them into the waste stream. Pollution control is a term used in environmental management. It means the control of emissions and effluents into air, water or soil. Without pollution control, the waste products from consumption, heating, agriculture, mining, manufacturing, transportation and other human activities, whether they accumulate or disperse, will degrade the environment. In the hierarchy of controls, pollution prevention and waste minimization are more desirable than pollution control.

Nanotechnology is being explored for its potential to provide new solutions to managing and cleaning up pollution in our air, water, and land, and improving the performance of conventional technologies used in cleanup efforts. The unique properties and characteristics of nanomaterials also lend themselves to being used to prevent pollution by reducing the release or emission of industrial hazardous waste and other pollutants [2].

Beneficial characteristics

The unique and potentially useful properties of nanomaterials include dramatically increased surface areas and reactivities, improved strength-weight ratios, increased electrical conductivity, and changes in color and opacity. Materials designed to take advantage of these properties are finding application in a variety of areas, such as electronics, medicine, and environmental protection. Nanomaterials and nanotechnology provide a powerful method of detection and treatment of trace pollutants in the environment [7]. The biggest source of potential environmental exposure is the use of nanoparticles in sanitizing contaminated groundwater and soil; concerns have been raised about the impact the high reactivity of nanoparticles might have on plants, animals, micro-organisms, and ecosystems [8].

This article is focused on three major areas of pollution prevention:

Products–products that are less toxic, less polluting, and wear-resistant;

Processes–processes that are more efficient and waste-reducing;

Energy and Resource Efficiency–processes or products that use less energy and fewer raw materials because of greater efficiency;

(1) Products

Examples of products with potential for preventing pollution include coatings that are free of volatile organic compounds and diisocyanates, safer surfactants, and self-cleaning surfaces.

Nanotechnology and nanomaterials can help create alternatives to light-emitting or absorbing applications that previously relied upon heavy metal-based semiconductors. Nanocomposites may be used in a variety of products, resulting in reduced need for the addition of flame retardant chemicals. In addition, products including a variety of tools, automobile and airplane components, and coatings can be made harder and more wear-, erosions, and fatigue-resistant than conventional counterparts.

A nanomaterial is a field which takes a materials science-based approach to nanotechnology. It studies materials with morphological features on the nanoscale, and especially those which have special properties stemming from their nanoscale dimensions. Nanoscale is usually defined as smaller than one tenth of a micrometer in at least one dimension, though this term is sometimes also used for materials smaller than one micrometer.

Nanoparticles or nanocrystals made of metals, semiconductors, or oxides are of particular interest for their mechanical, electrical, magnetic, optical, chemical and other properties. Nanoparticles have been used as quantum dots and as chemical catalysts [9].

Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at the nano-scale, this is often not the case. Size-dependent properties are observed such as quantum confinement in semiconductor particles, surface plasmon resonance in some metal particles and superparamagnetism in magnetic materials.

Nanoparticles exhibit a number of special properties relative to bulk material. For example, the bending of bulk copper (wire, ribbon, etc.) occurs with movement of copper atoms/clusters at about the 50 nm scale. Copper nanoparticles smaller than 50 nm are considered super hard materials that do not exhibit the same malleability and ductility as bulk copper. The change in properties is not always desirable. Ferroelectric materials smaller than 10 nm can switch their magnetization direction using room temperature thermal energy, thus making them useless for memory storage. Suspensions of nanoparticles are possible because the interaction of the particle surface with the solvent is strong enough to overcome differences in density, which usually result in a material either sinking or floating in a liquid.

Nanoparticles often have unexpected visual properties because they are small enough to confine their electrons and produce quantum effects. For example, gold nanoparticles appear deep red to black in solution. The often very high surface area to volume ratio of nanoparticles provides a tremendous driving force for diffusion, especially at elevated temperatures.

A nanocomposite can be defined as a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm), or structures having nano-scale repeat distances between the different phases that make up the material. In the broadest sense, this definition can include porous media, colloids, gels, and copolymers, but is more usually taken to mean the solid combination of a bulk matrix and nano-dimensional phase(s) differing in properties due to dissimilarities in structure and chemistry. The mechanical, electrical, thermal, optical, electrochemical, catalytic properties of the nanocomposite will differ markedly from that of the component materials. Size limits for these effects have been proposed,<5 nm for catalytic activity,<20 nm for making a hard magnetic material soft,<50 nm for refractive index changes, and<100 nm for achieving superparamagnetism, mechanical strengthening or restricting matrix dislocation movement.

Nanocomposites are composite materials in which the matrix material is reinforced by one or more separate nanomaterials in order to improve performance properties [10]. Nanocomposites are found in nature, for example in the structure of the abalone shell and bone. The use of nanoparticle-rich materials long predates the understanding of the physical and chemical nature of these materials.

Nanoparticulates may result in enhanced optical properties, dielectric properties, heat resistance or mechanical properties such as stiffness, strength, and resistance to wear and damage. In general, the nano reinforcement is dispersed into the matrix during processing. The percentage by weight (called mass fraction) of the nanoparticulate introduced can remain very low (on the order of 0.5% to 5%) due to the low filler percolation threshold, especially for the most commonly used non-spherical, high aspect ratio fillers (e. g. nanometer-thin platelets, such as clays, or nanometer-diameter cylinders, such as carbon nanotubes).

(2) Processes

Processes that could prevent pollution include more efficient industrial chemical production through the use of nanoscale catalysts, and the bottom-up self-assembly of materials, resulting in processing efficiency, reduction of waste in manufacturing, and stronger materials with fewer defects. In addition, the ability to enhance and tune chemical activity can result in catalysts that improve the efficiency of chemical reactions in automobile catalytic converters, power generation plants, and manufacturing facilities. A strong influence of nanochemistry on waste-water treatment, air purification, and energy storage devices is to be expected.

In this section the following processes will be covered: nanoparticles used as potent adsorbents, in some cases combined with magnetic particles to ease particle separation; nanoparticles used as catalysts for chemical or photochemical destruction of contaminants; nanosized zerovalent iron used for the removal of metals and organic compounds from water; and nanofiltration membranes.

Mechanical or chemical methods can be used for effective filtration techniques. One class of filtration techniques is based on the use of membranes with suitable hole sizes, whereby the liquid is pressed through the membrane. Nanoporous membranes are suitable for a mechanical filtration with extremely small pores smaller than 10 nm ("nanofiltration") and may be composed of nanotubes. Nanofiltration is mainly used for the removal of ions or the separation of different fluids [11]. Carbon nanotubes have been arranged to form a hollow monolithic cylindrical membrane, which was efficient for the removal of bacteria or hydrocarbons and that can easily be regenerated by ultrasonication or autoclaving. Nanofiltration has been reported as a suitable method for groundwater treatment [12].

Magnetic nanoparticles offer an effective and reliable method to remove heavy metal contaminants from waste water by making use of magnetic separation techniques. Using nanoscale particles increases the efficiency to absorb the contaminants and is comparatively inexpensive compared to traditional precipitation and filtration methods. This approach has been proposed with magnetite (Fe3O4), maghemite (g-Fe2O3) and jacobsite (MnFe2O4) nanoparticles for removal of chromium(VI) from wastewater [13,14]. Water-soluble CNTs have been functionalized with magnetic iron nanoparticles for removal of aromatic compounds from water and easy separation from water for re-use [15].

Some water-treatment devices incorporating nanotechnology are already on the market, with more in development. Low-cost nanostructured separation membranes methods have been shown to be effective in producing potable water in a recent study. Nanoscale iron particles have also shown potential as a detoxifying agent for cleaning environmental contaminants from brownfield sites.

(3) Energy and resource efficiency

The efficiency of resource use could be improved through nanotechnologies such as light-emitting diodes. Nanocomposites are valued in automotive applications for their improved physical properties and their ability to produce parts with reduced weight (leading to improved fuel efficiency). Carbon nanotubes added to inherently non-conductive polymers allow nanocomposite parts to be painted using electrostatic methods, significantly reducing paint emissions. Conventional and rechargeable batteries are used in a growing number of portable electronic devices, and nanomaterials are beginning to make an impact by enabling batteries to last longer and withstand an increased number of charging cycles. In addition, nanomaterials can be used to make aerogels: porous and extremely lightweight materials that can save energy when used as insulation [16].

Nanotechnology could potentially have a great impact on clean energy production. Research is underway to use nanomaterials for purposes including more efficient solar cells, practical fuel cells, and environmentally-friendly batteries. The most advanced nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving (by better thermal insulation for example), and enhanced renewable energy sources.

Current commercially available solar cells have low efficiencies of 15-20%. Research is ongoing to use nanowires and other nanostructured materials with the hope to create cheaper and more efficient solar cells than are possible with conventional planar silicon solar cells. It is believed that these nanoelectronics-based devices will enable more efficient solar cells, and would have a great effect on satisfying global energy needs.

Another example for an environmentally friendly form of energy is the use of fuel cells powered by hydrogen. Probably the most prominent nanostructured material in fuel cells is the catalyst consisting of carbon supported noble metal particles with diameters of 1-5 nm. Suitable materials for hydrogen storage contain a large number of small nanosized pores.

Nanotechnology may also find applications in batteries. Because of the relatively low energy density of conventional batteries, the operating time is limited, and a replacement or recharging is needed, and the huge number of spent batteries represents a disposal problem. The use of nanomaterials may enable batteries with higher energy content or supercapacitors with a higher rate of recharging, which could be helpful for the battery disposal problem.

An important subfield of nanotechnology related to energy is nanofabrication. Nanofabrication is the process of designing and creating devices on the nanoscale. Creating devices smaller than 100 nanometers opens many doors for the development of new ways to capture, store, and transfer energy. The inherent level of control that nanofabrication could give scientists and engineers would be critical in providing the capability of solving many of the problems that the world is facing today related to the current generation of energy technologies [17].

People in the fields of science and engineering have already begun developing ways of utilizing nanotechnology for the development of consumer products. Benefits already observed from the design of these products are an increased efficiency of lighting and heating, increased electrical storage capacity, and a decrease in the amount of pollution from the use of energy. Benefits such as these make the investment of capital in the research and development of nanotechnology a top priority.

Environmental risks

The use of nanoparticles in environmental applications will inevitably lead to the release of nanoparticles into the environment. Assessing their risks in the environment requires an understanding of their mobility, bioavailability, toxicity, and persistence. Whereas air-borne particles and inhalation of nanoparticles have attracted a lot of attention [18], much less is known about the possible exposure of aquatic and terrestrial life to nanoparticles in water and soils [19]. A consistent body of evidence shows that nanosized particles can be taken up by a wide variety of mammalian cell types, are able to cross the cell membrane and become internalized. Nanoparticles are also toxic to aquatic organisms, both unicellular (e. g. bacteria or protozoa) and animals (e. g. daphnia or fish) [20].

These results from studies show that certain nanoparticles will have effects on organisms on the environment, at least at elevated concentrations. The next step towards an assessment of the risks of nanoparticles in the environment will, therefore, be to estimate the exposure to the different nanoparticles.

CONCLUSION

Nanotechnology is an emerging science with broad applications and potential benefits. The aim of this review is to give an overall perspective of the use of nanotechnology to solve potential issues of environmental pollution. Nanomaterials have properties that enable both chemical reduction and catalysis to mitigate the pollutants of concern. While nanomaterials have beneficial applications, they also raise concerns over potential implications for human health and the environment. Bioaccumulation potential, toxicity, worker and community exposure, and ultimate fate are among the concerns that merit consideration. The pursuit of pollution prevention applications of nanotechnology should be undertaken with consideration of the potential impacts across the entire lifecycle of the nanomaterials, including production, use, and end-of-life disposition. A broad consideration of the benefits and potential impacts can help to ensure that economic and environmental benefits are maximized while minimizing the likelihood of unintended adverse consequences.

CONFLICT OF INTERESTS

Declared none

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