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Nanotechnologies for purification and remediation of water

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ABSTRACT

The nano-enabled technologies for water purification include a variety of different types of membranes and filters based on carbon nanotubes, nanoporous ceramics, magnetic nanoparticles, nanosized zerovalent iron used for the removal of metals and organic compounds from water, and other nanomaterials. Nanosensors, such as those based on titanium oxide nanowires or palladium nanoparticles are used for analytical detection of contaminants in water samples. A careful weighing up of the opportunities and risks of nanotechnology with respect to their effects on the environment and health is needed.

KEYWORDS

Nanofiltration;
Water remediation;
Nanomaterials;
Nanosensor.

INTRODUCTION

Clean water is a requirement for all properly functioning societies worldwide, but is often limited. New approaches are continually being examined to supplement traditional water treatment methods. These need to be lower in cost and more effective than current techniques for the removal of contaminants from water. Nanotechnology bridges scientific disciplines such as chemistry, biology, physics, and engineering and provides a wide range of applications. Environmental nanotechnology is considered to play a key role in the shaping of current environmental engineering and science[1]. Nanotechnology utility in purification of water is now being realized. It has been found that it is much easier to deal with water purification and desalination at nano scale. The options for treating water using nanotechnologies depend on the demand. Everything that is undesirable in drinking water, for example, dirt, bacteria, viruses, organic compounds, pesticides, heavy metals, radionuclides, nitrate, phosphate, calcium, sulphate, etc. can be removed using certain processes[2,3]. Nanotechnology has been used for some time in the preparation of drinking water with membrane filters, and its potential is enormous. There are no environmental risks as long as nanopores are used.

Unlike membranes, the use of nanoparticles in water treatment is still in its infancy. Nanoparticles are now also playing a role in water treatment, because they have a large specific surface making them suitable as adsorption material that can efficiently remove organic as well as inorganic substances such as nitrate from water. Water purification using nanotechnology exploits nanoscopic materials such as carbon nanotubes and alumina fibers for nanofiltration, as well as nanocatalysts and magnetic nanoparticles. Nanosensors, such as those based on titanium oxide nanowires or palladium nanoparticles are used for analytical detection of contaminants in water samples[4]. The nano-enabled technologies include a variety of different types of membranes and filters based on carbon nanotubes, nanoporous ceramics, magnetic nanoparticles and other nanomaterials. Nanofiltration membranes can produce potable water from the brackish groundwater[5].

NANOFILTRATION TECHNOLOGIES

Nanofiltration technologies are widely used for the production of safe drinking water, and for the recovery of reusable water from various industrial effluent streams. The pore sizes of the membranes in nano filters are below 100 nanometers and thus even small salts or viruses find it hard to pass through. The basic principle of nano-filtration lies in the fact that the chemical properties of basic elements involved tend to be different and easier to manipulate at a molecular or atomic level. Hence nano-filtration tends to be a better process. Besides, the operating costs of nano-filtration are lower. There have been concerns regarding toxicity of nano particles in water purification. Toxicity aspects of nanofiltration need to be checked[6].

Nanotechnology offers the potential of novel nanomaterials for treatment of surface water, groundwater, and wastewater contaminated by toxic metal ions, organic and inorganic solutes, and microorganisms. The current research on different nanomaterials (nanostructured catalytic membranes, nanosorbents, nanocatalysts, and bioactive nanoparticles), their application in water treatment, purification, disinfection, and toxicological effects of engineered nanomaterials on humans and the environment has been reported[7].

The potential impact areas for nanotechnology in water applications are divided into three categories:

i) **Treatment and remediation**: Here, nanotechnology has the potential to contribute to long-term water quality, availability, and viability of water resources, such as through the use of advanced filtration materials that enable greater water reuse, recycling, and desalinization.

ii) **Sensing and detection**: In this category, the focus is on the development of new and enhanced sensors to detect biological and chemical contaminants at very low concentration levels in the environment, including water.

iii) **Pollution prevention**: Pollution prevention by nanotechnology refers on the one hand to a reduction in the use of raw materials, water or other resources and the elimination or reduction of waste and on the other hand to more efficient use of energy or involvement in energy production[8]. Sorbents are widely used in water treatment and purification to remove organic and inorganic contaminants. In this context, the use of nanoparticles may have advantages over conventional materials due to the much larger surface area of nanoparticles on a mass basis. Several types of nanoparticles have been investigated as adsorbents: metal-containing particles, mainly oxides, carbon nanotubes and fullerenes, organic nanomaterials and zeolites. CNTs have attracted a lot of attention as very powerful adsorbents for a wide variety of organic compounds from water. Examples include dioxin, polynuclear aromatic hydrocarbons (PAHs), DDT and its metabolites, PBDEs, chlorobenzenes and chlorophenols, trihalomethanes, bisphenol A and nonylphenol, phthalate esters, dyes, pesticides (thiamethoxam, imidacloprid and acetamiprid) and herbicides such as sulfuron derivatives, atrazine and dicamba. Oxide–CNTcomposites have been explored for the removal of metals[9], and also of anions such as arsenate and fluoride[10,11]. 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[12].

NANOFILTRATION

Nanofiltration membranes (NFmembranes) are used in water treatment for drinking water production or wastewater treatment[13]. NF membranes are pressure-driven membranes with properties between those of reverse osmosis and ultrafiltration membranes and have pore sizes between 0.2 and 4 nm. NF membranes have been shown to remove turbidity, microorganisms and inorganic ions such as Ca and Na. They are used for softening of groundwater (reduction in water hardness), for removal of dissolved organic matter and trace pollutants from surface water, for wastewater treatment (removal of organic and inorganic pollutants and organic carbon) and for pretreatment in seawater desalination. Carbon nanotubes have been arranged to form a hollow monolithic cylindrical membrane[14], which was efficient for the removal of bacteria or hydrocarbons and that can easily be regenerated by ultrasonication or autoclaving. Applications of nanofiltration membranes in water treatment were reviewed[15].

A comprehensive review has been reported, for the use of NF membranes in water and wastewater treatment, NF separation mechanisms, ionic components removal from brackish and sea water, use of brine disposal, and renewable energy for NF efficiency. In addition, NF was used as a pre-treatment step in the desalination process.

Nanofiltration (NF) membranes have applications in several areas. One of the main applications has been in brackish and sea water treatment for drinking water production as well as for wastewater treatment. The introduction of NF as a pre treatment is considered a breakthrough for the desalination process. NF membranes have the ability to remove turbidity, hardness, fluoride and nitrate as well as a significant fraction of dissolved salts. Desalination can be performed with a significantly lower operating pressure and becomes a much more energy-efficient process. The application of NF for water treatment and as a pre-treatment step for low energy consumption processes such as photovoltaic-powered units were reported[16].

NANOMATERIALS AND WATER FILTRATION

Membrane processes are considered key components of advanced water purification and desalination technologies and nanomaterials such as carbon nanotubes, nanoparticles, and dendrimers are contributing to the development of more efficient and cost-effective water filtration processes. There are two types of nanotechnology membranes that could be effective: nanostructured filters, where either carbon nanotubes or nanocapillary arrays provide the basis for nanofiltration; and nanoreactive membranes, where functionalized nanoparticles aid the filtration process. The researchers also note that advances in macromolecular chemistry such as the synthesis of dendritic polymers have provided opportunities to refine, as well as to develop effective filtration processes for purification of water contaminated by different organic solutes and inorganic anions.

NANOTECHNOLOGIES FOR WATER REMEDIATION

Remediation of contaminated water – the process of removing, reducing or neutralizing water contaminants that threaten human health and/or ecosystem productivity and integrity – is a field of technology that has attracted much interest recently. Examples of various nanoparticles and nanomaterials that could be used in water remediation include: zeolites, carbon nanotubes, self-assembled monolayer on mesoporous supports (SAMMS), biopolymers, single-enzyme nanoparticles, zero-valent iron nanoparticles, bimetallic iron nanoparticles, and nanoscale semiconductor photocatalysts.

NANO-IRON FOR GROUNDWATER REMEDIATION

Certain nanoparticles can also react chemically with pollutants and thus destroy them. This occurs when groundwater that has been polluted with chlorinated hydrocarbons is decontaminated with nano-iron. The pollutants react chemically with the iron, which turns them into harmless substances. Until now, normal iron swarf has been used that was placed in the underground in the form of a permeable barrier allowing the groundwater to pass through it. Higher reactivity and lower outlay can be expected if nano-iron particles are pumped into groundwater through bore holes. The particles are coated with organic substances so that they do not adsorb on surfaces. In this way they remain mobile and are distributed more evenly in the groundwater.

BIOACTIVE NANOPARTICLES FOR WATER DISINFECTIONS

Nanotechnology may present a reasonable alternative for development of new chlorine-free biocides. Among the most promising antimicrobial nanomaterials are metallic and metal-oxide nanoparticles, especially silver, and titanium dioxide catalysts for photocatalytic disinfections.

NOBLE METAL NANOPARTICLES AND WATER PURIFICATION

The application of noble metal nanoparticle based chemistry for drinking water purification has been reported for three major types of contaminants: halogenated organics including pesticides, heavy metals, microorganisms[17].

Tiny particles of pure silica coated with an active material could be used to remove toxic chemicals, bacteria, viruses, and other hazardous materials from water much more effectively and at lower cost than conventional water purification methods, according to researchers writing in the current issue of the International Journal of Nanotechnology[18].

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