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The Role of Nanomaterials in Water Purification.

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ABSTRACT

Water is the most important concern of today's life. The generalized scenario of the world is that most of the people are dying due to drinking of unsafe water. Industrial expansion, rising population & impact of change in climate are responsible for increasing impurities in drinking water. In this paper we have discussed the methods of Nanotechnology for water purification and water research where various membrane processes like nanofiltration, ultrafiltration, reverse osmosis, and nanoreactive membranes are used & the impact of using nanotechnology for water purification on human health & environment. The modular, multifunctional, and high-efficiency processes enabled by nanotechnology can be broadly applicable in both industrialized and developing countries, by enabling the retrofitting of aging infrastructure and the development of high-performance, low-maintenance devices that facilitate differential water treatment and reuse. The convergence of nanotechnology with environmental microbiology is a fertile interdisciplinary research area that could expand the limits of technology, enhance global health through safer water reuse, serve as an innovative ecosystem to nurture intellectual entrepreneurs, and contribute towards sustainable and integrated urban water management.

Keywords: nanomaterial, water, purification.

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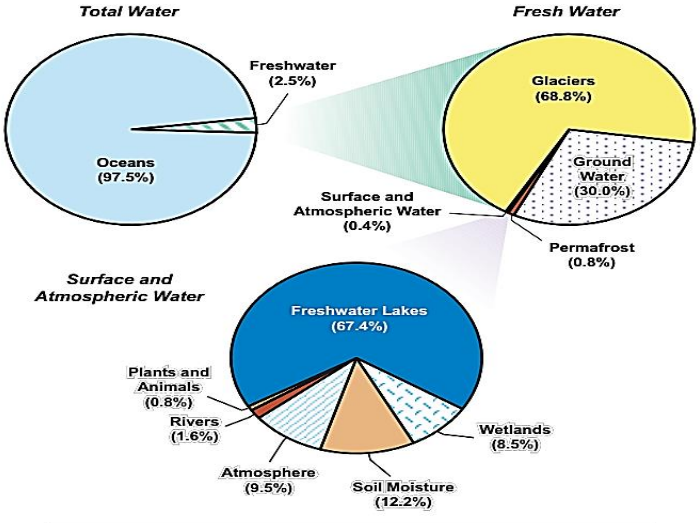
INTRODUCTION

Many of the current world problems like high chemical contamination in air, water and soil including high carbon compounds, are related to this fast pace of population growth. Current world population is about 6.5 billion and increasing at an alarming rate and is projected to be 9 million by 2050[1]. Efforts to tackle the population related issues has resulted in severe damage to the ecosystem thereby creating health hazards through environmental pollution. Increased demand for more habitation led to large-scale deforestation and decreased agricultural land, lowering the yield. The production level of food grains is of concern as it has been showing a downward trend over the last decade. Further, extensive use of persistent chemical pesticides to boost agriculture production has also adversely affected our ecosystem and is known to have contaminated ground water [2,3]. Similarly, industrialization is leading to increase in per capita consumption of available natural resources. Out of1,386 million cubic kilometers (km^3) of water on Earth, 97%is saline and 99.7% of the freshwater is trapped in ice caps and glaciers, or found in groundwater (one third). Only about 0.1 million km^3 of water is above ground in lakes, swamps and rivers, and about 13,000 km^3 in the atmosphere [4].

Surface water has not increased for the past 20 years, and simultaneously, groundwater tables have been dropping [5]. Water is a fundamental requirement for life. The availability of fresh water is crucial for life sustaining activities like drinking, cooking, cleaning, agriculture, etc. Nature has its own mechanism for water recycling to provide us with adequate quantity of fresh water with consumable purity level. Modern human activities have however disrupted the balance between the usage and natural purification processes leading to a shortage of potable water. Most of the natural resources of drinking water are found to be contaminated with diverse toxic materials and pathogenic microorganisms[2] 700 million people across the globe face water scarcity, and it is estimated that this problem will touch 1.8 billion people by 2025 [6]. According to a World Health Organization (WHO) report, water borne diseases kill nearly 12 million people every year [7]. About 90% of all diseases occurring in developing countries are related to the consumption of impure water leading to nearly 4 billion reported cases of diseases contracted from water in the world [8].

Worldwide, there are nearly 4 billion reported cases of diseases contracted from water. ‘Low carbon water’ through artificial methods has therefore become a necessity for the survival of the human race. Disinfection of drinking water is currently being carried out through physical and chemical techniques like chlorination, ozonation, UV treatment, etc. Each of the conventional water disinfection processes has limitations generating concerns about their mass scale application [2, 3, 9, 10].



Source: United Nations Educational, Scientific, and Cultural Organization (UNESCO), Cambridge Energy Research Associates.
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Fig.1 Percentage of Water resources across the globe.

Advanced nanotechnology offers unprecedented opportunities for progress—defeating poverty, starvation and disease and expanding human capacities. Nanotechnology is defined as the ability to understand, control, and manipulate matter at the level of individual atoms and molecules, as well as at the "supramolecular" level involving clusters of molecules (in the range of about 0.1 to 100 nm), in order to create materials, devices, and systems with fundamentally new properties and functions because of their small structure [11].

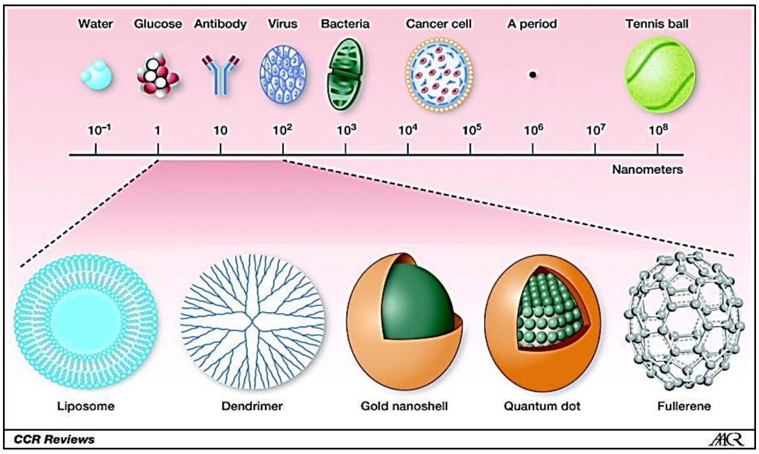


Fig.2 Major nanostructures

Application of nanotechnology that results in improved waste treatment options might include removal of the finest contaminants from water (< 300 nm) and "smart" materials or reactive surface coatings with induced specificity to a certain pollutant that destroy or immobilize toxic compounds and pathogens.

WATER PURIFICATION METHODS

Reverse Osmosis

In this filters have a pore size around0.0001 micron. After water passes through a reverse osmosis filter, it is essentially pure water. In addition to removing all organic molecules and viruses, reverse osmosis also removes most minerals that are present in the water. Reverse osmosis removes monovalent ions, which means that it desalinates the water. To understand how reverse osmosis works; it is helpful to understand osmosis occurs when a semi-permeable membrane separates two salt solutions of different concentrations. The water will migrate from the weaker solution to the stronger solution, until the two solutions are of the same concentration, because the semi-permeable membrane allows the water to pass through, but not the salt. In the following diagram, (a) procedure is shown. In reverse osmosis, the two solutions are still separated by a semi-permeable membrane, but pressure is applied to reverse the natural flow of the water. This forces the water to move from the more concentrated solution to the weaker. Thus, the contaminants end up on one side of the semi-permeable membrane and the pure water is on the other side[12].

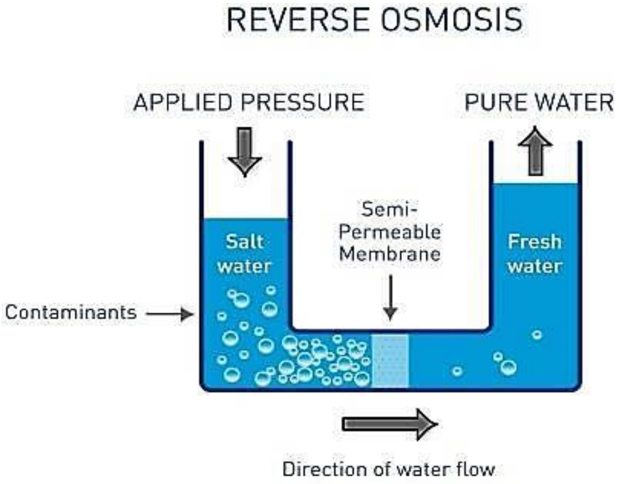


Fig.3. Reverse Osmosis process

NANOFILTRATION FOR WATER AND WASTE WATER TREATMENT

Nanofiltration (NF) is a new type of pressure driven membrane process and used between reverse osmosis and ultra filtration membranes. The most different specialty of NF membranes is the higher rejection of multivalent ions than monovalent ions. NF membranes are used in softening water, brackish water treatment, industrial waste water treatment and reuse, product separation in the industry, salt recovery and recently desalination as two pass NF system. In this chapter, a general overview of nano filtration membranes, membrane materials and manufacturing techniques, principles such as performance and modeling, module types, membrane characterization and applications on water and waste water treatment were given. The salt separating mechanism of NF membrane are similar to nonporous RO membrane where solute & solvent fluxes are uncoupled contrast to convective solute transport in porous UF membrane The molecular weight cut off value of NF is in the range of 150-300 Da with unique property of higher rejection of multivalent ions than monovalent ions The high quality of RO permeate is perfect however it requires high feed press., RO permeate is some times mix with feed water to balance the ions & make stable drinkable water. NF membranes have taken away all these disadvantages of RO membranes which was a further development of RO membrane [13].

NANO PARTICLES FOR WATER PURIFICATION

Carbon Nanotubes

Activated carbon has been applied for decades as a sorbent material to clean drinking water, as well as wastewaters of industrial, petrochemical, residential, and commercial operations. This usage occurs primarily because it is extremely cheap, contains a wide variety of various surface functional groups (including carboxyl, quinone, phenol, and lactone), and has a high surface area for adsorption (up to 2000 m^2/g), stemming from the nano-porous nature of the material itself, with pores as small as 2 – 50 nm. Activated carbon systems are usually made in the form of cartridges or columns where water is passed through via gravity or a pressure-driven method. As the water flows through the carbon, contaminants found in the water come into contact with the carbon and are adsorbed by the carbon material. Furthermore, this carbon can be regenerated simply by repeating the original production process, where the heat and oxidizing gas drive off any sorbed contaminant. However, the further development of carbon into carbon nanotubes (CNTs), whose usage has exploded onto the market in the past two decades [14], with the promise that they can eventually lead to at least partial substitution of activated carbon in the marketplace. Studies have already proven that CNTs can vastly outperform typical activated carbon with the adsorption of various organic pollutants, as much as 99% greater in certain cases[15], and 3-4 times higher for heavy metals, such as Pb^{2+}, Cu^{2+}, and Cd^{2+} [16]. Furthermore, CNTs provide a sustainable approach, in that as the metals sorb to the surface functional groups found on the carbon, the metals can subsequently be released and collected simply by adjusting the pH of the solution[17]. In short, these CNTs consist of graphitic cylinders made up of networks of hexagonal carbon linkages that can be as small as 2 nm in diameter[18] and in spite of their small diameter, CNTs can have extremely high length/diameter ratios. The advantage that CNTs possess over traditional activated carbon is that while retaining their high surface area, the structure is easily controllable and well-defined, offering fine-tuning of the compound for application purposes. It is these abilities to control size and length of the CNT, to open/close the ends of the CNT, and to functionalize the surface of the CNT with various metals, functional groups (e.g. alcohol, carboxylic, or carbonyl groups) that provide for extremely effective adsorption properties. Hence, water treatment with CNTs can be very effective and is used primarily as an adsorbent material, applied to a wide range of compounds such as various heavy metals (As, Cd, Pb, etc.), organic pollutants (benzene, toluene, halogenated solvents, herbicides, etc.), and inorganic contaminants, as well as chlorinated organics like 1,2-dichlorobenzene and trichloroethylene, polycyclic aromatic hydrocarbons, phenolic compounds, surfactants, herbicides like atrazine, antibiotics like tetracycline, and many others[19]. However, being that CNTs are to date quite expensive, effective use of this technology has been limited to the adsorption of more complex molecules (e.g. polar aromatics, pharmaceuticals, and pesticides) that are not as readily adsorbed using traditional methods. Regardless, the market is seeing a shift into CNT-based water treatment technologies. Foremost is their incorporation into membrane materials, not only to adsorb contaminants, but also to provide mechanical strength. Current research has also seen a shift into using CNT-incorporated membranes for lower-cost seawater desalination purposes; however, realization of this remains yet to be determined. Some companies have also introduced prototype portable water filters containing CNT meshes or sheets in to the market, capable of treating polluted water sources. These portable water CNT water filters have been targeted mainly for military use, disaster relief, remote-area travelling, and also as an attachment at the tap for residential use. Given the high cost of CNTs, some focus has been diverted towards a similar, but cheaper material: graphite oxide nanosheets, which have exhibited similar adsorption characteristics towards organics and metals[20].

Chitosan

Chitosan is a polysaccharide compound derived from naturally occurring peptides called chitin, which is very similar to cellulose and the next most abundant naturally occurring fibre after cellulose. It comes from a wide range of sources in the environment, most notably the shells of crustaceans, insects, and mushrooms. Being that it can be made cheaply from already naturally occurring sources, chitosan has an advantage that it can be operated at low costs in a low-tech manner. This ability also draws the appeal of chitosan towards rural areas and developing countries. In addition to being an appealing bio-sorbent, chitosan also displays antimicrobial properties. The particular antimicrobial mechanism is the formation of tight nanoscale pathways that allow for molecular transport across cell membranes, which ultimately can lead to the collapse of a cell [21]. It is also for this reason that nanoscale chitosan is so widely used in the biomedical and drug delivery markets. More specific to water disinfection, however, this process can lead to cell membrane damage as well as chelation of trace metals within the cell that are necessary for life. Given this phenomenon, it was made possible to custom-make these nano-structures for specific applications, whether that be for removal bacteria, viruses, or fungi[21]. Chitosan, due to its high hydrophilicity, presence of surface functional groups, and flexible nature, is also used as a bio-sorbent for many different contaminants, namely heavy metals, dyes, phenols, and certain anions[22]. Some of the adsorption rates for various compounds include numbers in the range of hundreds of mg of dye for each gram of chitosan and reaching as high as 1000 mg dye per gram chitosan, 100 – 200 mg of phenol per gram chitosan, or as much as 100 mg of nitrate per gram chitosan . The unique nature of these particles gives chitosan the ability to be used in applications like flocculation in water and wastewater treatment as well as the disinfection of drinking water. Use of nanoscale chitosan for disinfection remains slightly elusive for large-scale operations, unless incorporated into a membrane; however, its use in coagulation and flocculation operations is increasing and appears to be the most promising use for it. It is promising because it is extremely efficient at coagulating organic and inorganic compounds and chelating highly toxic heavy metals; and in the process, the particles grow in size to a point where the unknown risks coming from their nano-size become irrelevant.

Zeolites

Natural zeolites are found in regions all over the world, coming primarily from minerals in volcanogenic sedimentary rock. Zeolites, which can be generally defined as highly crystalline and highly porous inorganic materials, are comprised primarily of silicon and aluminium and oxygen[23]. There are at least 50 natural zeolites and there are well over 150 synthetic versions of zeolites being produced for various purposes. Natural zeolites and conventionally synthesized zeolites typically range from 1-10 µm; however, zeolites can be synthesized on the nanoscale, from 5-100 nm[24] most often by grinding e.g. using a ball-milling procedure in a wet environment. When synthesized in this and other similar manners, these nanoscale zeolites can have targeted and uniform crystal structures, depending on the application. These nanoscale versions of zeolites have substantially higher surface areas and smaller diffusion path lengths than non-nano zeolites[25]. It is their robustness towards mechanical and chemical stresses that gives zeolites such proliferation in the catalysis, separation, and ion-exchange markets[26]. Specifically, what makes zeolites so great for sorption and ion exchange is the high density of ion exchange sites (e.g. Na^+) and porosity. Due to this phenomenon, nanoscale zeolites have been given much attention to their incorporation into various types of membranes to aid in the desalination process of seawater and brackish water sources within the past decade. For example, this ion exchange mechanism was applied towards heavy metal removal in acid mine drainage[27] and electroplating wastewaters[28].

Iron oxides and zero valent iron

Iron, and iron based particles, are by far the most prolific nanoparticles used in the field of water treatment due to iron being ubiquitous in the earth’s crust, cheap to manufacture, environmentally safe, and also a very effective contaminant reductant when converted to its zero valent form (Fe0). Hence, the uses of iron-based nanoparticles cover various sorption applications and reductive decontamination applications. Sorption of contaminants stems from the complexation of the dispersed metals and the oxygen in the corresponding metal oxides[29]. Furthermore, as the particle size of these iron-based particles is reduced, the adsorption capacity has the potential to drastically increase. To date, applications involving the use of (nano) iron oxides for the adsorption and subsequent magnetic removal of pollutants include removal of bacteria, arsenic, and organic contaminants, among others[30,31] . Perhaps most notably, drinking water treatment by use of magnetic iron oxide nanoparticles to adsorb arsenic and subsequently be removed by a simple magnet was named one of Forbes Magazine's “Top Five Nanotech Breakthroughs of 2006.” This could prove to be one of the cheapest and most effective techniques to remove arsenic from drinking water, which could drastically improve the quality of life for tens of millions of people around the world that suffer from arsenic-laden water, in places like India and Bangladesh, for example. In addition to iron being an extremely successful adsorbent material, when converting it into Fe0, it becomes highly reactive. The basic mechanism is that as the Fe0 particle oxidizes from an iron-oxide shell, electrons are released and water is broken down into hydroxyl radicals and protons, which creates an environment capable of degrading many pollutants (see Figure 4 below).

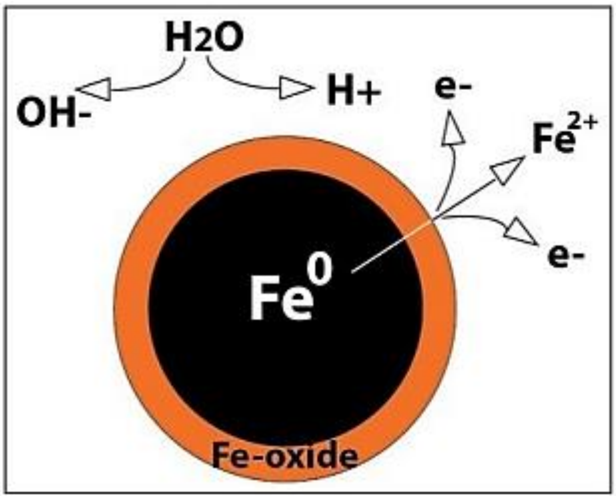


Fig 4: Basic reaction mechanism of nzvi particles in water to form pollutant-reducing conditions.

Therefore, nano-Fe0 (nZVI) technologies must take great care in that the reactivity of the particles is not lost before the particles themselves are oxidized and more or less inert. Nonetheless, in 2014, papers dealing with nZVI accounted for 15.8% of all the papers mentioning ZVI [32]. Although the bulk of work performed has to deal with the use of *in situ* applications of nZVI in the form of soil and groundwater remediation , there are plenty of applications in industrial wastewater, drinking water, or “pump-and-treat” operations for groundwater. For example, when combing nZVI onto a kaolin support, these particles were able to remove 98.8% of Pb^{2+} and 99.8% of total chromium in electroplating wastewater streams[33]. Moreover, there are many companies on the market, like NanoIron s.r.o. in the Czech Republic, which make nZVI powders and slurries that are designed to not only be injected into the ground for soil remediation, but also for the pump-and-treat applications and treating industrial sewage loaded with dyes and various other contaminants. Therefore, although not totally commercial at this point, the future nZVI for pump-and-treat operations lies in one of two forms, that involve attaching the nZVI to some other base material. The first is maintaining nZVI in the form of a slurry and adding that to an already existing treatment operation. The second is by attaching nZVI to a larger particle or granule (e.g. kaolin or activated carbon) and forcing contaminated water through a column as a flow-through system.

Silver and gold nanoparticles

Silver (Ag) has been used to improve human health and conditions for centuries and its toxicity towards various microorganisms has been extensively studied since the 1970s[34] , resulting in the use of silver antimicrobials in many bio-medical applications [35]. This notion led the United States National Aeronautics and Space Administration (NASA) to develop a lightweight device that released silver ions in the water supply of a spacecraft that would keep the drinking water bacteria-free, thus eliminating the need for chlorine. Building on this technology, many companies later used similar methods to deliver silver ions into swimming pool waters, keeping them free of bacteria. Such devices are now frequently used in private pools all over Denmark and the rest of the world. This history has led to the development of silver being engineered as nanoparticles, and is currently the most utilized nanomaterial for disinfection and anti-microbial applications. Most notably available on the commercial market is the use of silver nanoparticles (AgNPs) for small-scale personal water purifiers, the type typically used by hikers and backpackers in the wilderness. Using AgNPs this way (usually as part of a membrane system in combination with activated carbon) eliminates the need for more toxic and foul-tasting disinfection methods like iodine tablets. The idea driving the use of (AgNPs) is that there is a release of biocidal silver ions (Ag+) that attach to and alter the membrane permeability of a cellular organism, which can subsequently attack the thiol groups in proteins or the phosphates in DNA[36]. In this process, these AgNPs then break down the respiratory chain and cell division, which eventually leads to the death of the cell[37].

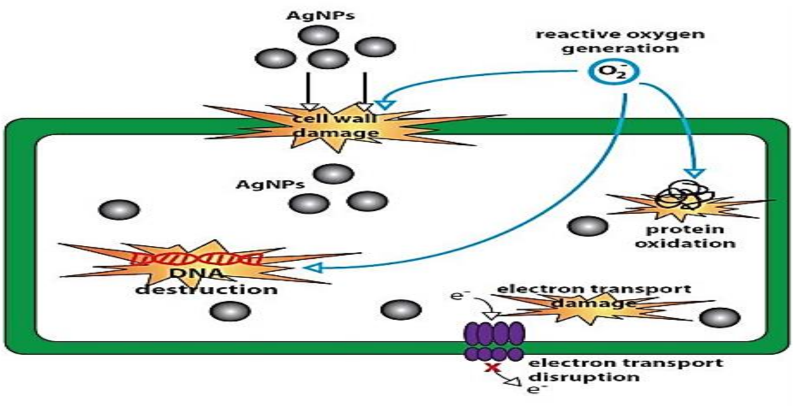


Fig 5: Various antimicrobial activities using silver nanoparticles.

In this context, AgNPs have been used as a disinfectant for Gram-negative organisms (e.g. *E. coli,V. cholerae, Salmonella*), Gram-positive organisms (e.g. *Staphylococcus*), and many other pathogens in drinking water and wastewater treatment[38,39]. Furthermore, the versatility of AgNPs comes with their ability to be incorporated into a plethora of different materials. These materials include zeolites, dendrimers, and membranes, among others, which are then incorporated into disinfection treatment systems as particles in bulk solution or as a means of filtering. Although the incorporation of AgNPs into other materials makes them substantially cheaper, the particles themselves remain quite expensive; a price of nearly 180,000 DKK per kg for a 5% dispersion of AgNPs has been quoted. This number is obviously extremely high, and further optimization of the technology, primarily incorporation into other particles or membranes, remains the only practical method of treatment technologies. Even though AgNPs are very effective and can be sufficiently immobilized in many materials, the problem of re-dissolution of the particles remains, and consequently that of silver release control and further replenishment of AgNPs. This last statement is important in the further implementation of silver for water treatment purposes, as it is that the Danish Ministry of the Environment has set a limit of only 10 µg/L of silver at the tap. However, even if silver is released into the water treatment and distribution network from any of these sources, it is usually effectively removed during the municipal wastewater treatment process as silver can be readily transformed into non-dissolvable silver sulphide (Ag_2S).

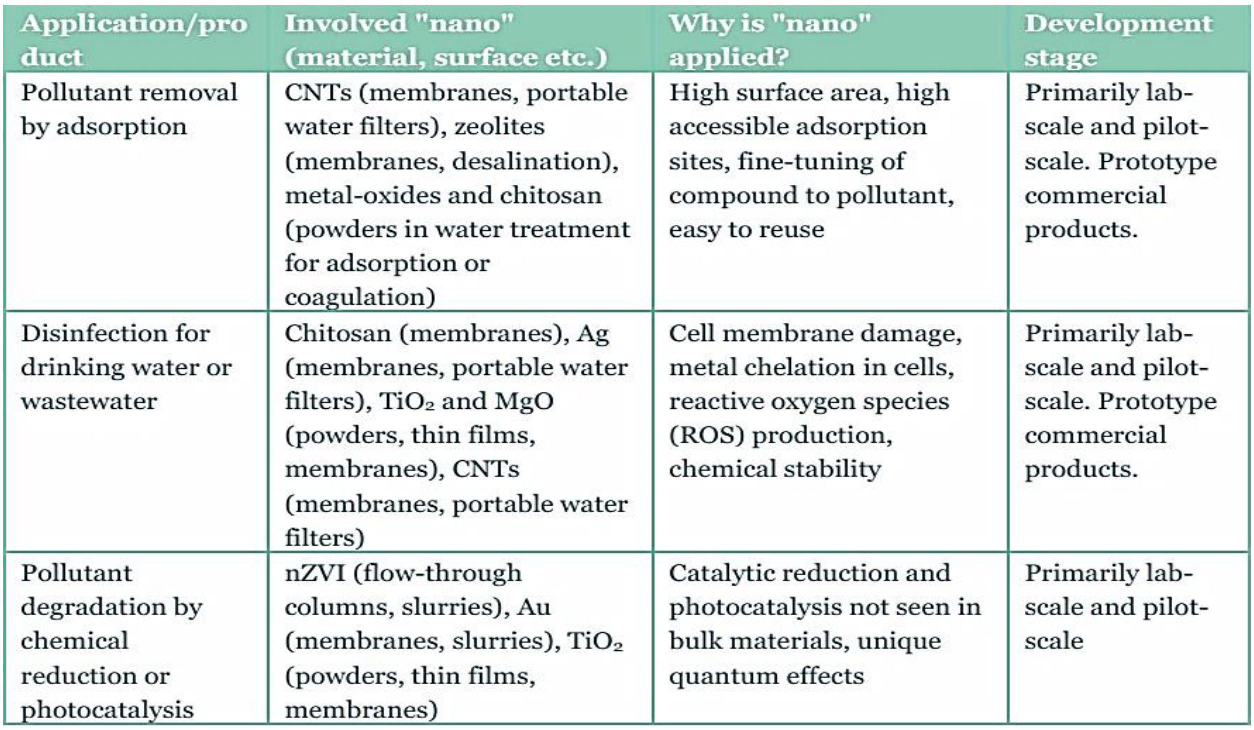
Although the current price of gold (Au) makes the notion of using gold nano-particles (AuNP) for water treatment purposes seem daunting at first, the unique properties that gold exhibits on the nanoscale make the idea more plausible, although the economics may make the use of gold nanoparticles (AuNPs) unrealistic in the long run. Even so, given that AuNPs have the ability to remove such extremely harmful compounds like mercury or trichloroethylene (TCE), they may be economically justified. For example, when combining AuNPs with a simple citrate molecule, it is possible to adsorb and remove mercury from contaminated river water[40]. This works in a multi-step process where the citrate reduces the AuNPs, which then act as a catalyst to reduce mercury and allow for it to be trapped by other metals (e.g. copper or iron) in solution. Moreover, when combined with another noble metal, such as palladium, AuNPs exhibit extremely high catalytic reduction capacity towards some hazardous compounds, such as trichloroethylene [41] and nitrite [42]. Various other operations employing AuNPs are proving effective for removal of certain halocarbons, BTEX compounds, and sulphur-containing organic contaminants (i.e.

pesticides). However, as with AgNPs, the problem of cost remains with AuNPs. Addition of catalytic noble metals and/or a stabilizing agent into which to incorporate the gold remains the only current method to ensure AuNPs can be used at an appropriate cost level.

Metal oxides of titanium, magnesium, and zinc

The use of metal oxide nanomaterials for treating water is not limited only to iron oxide , other metal oxides like, oxides of magnesium (Mg), zinc (Zn), and titanium (Ti) are also the subject of much attention. Of all the metal oxides, titanium dioxide (TiO_2) is perhaps the most versatile, and possibly the most widely used with the exception of iron oxides. TiO_2, by means of photocatalysis, is capable of adsorbing metals, organic contaminants, and various other compounds, disinfecting water contaminated with a wide range of bacteria, and degrading certain pollutants. An ideal example of how TiO_2 can adsorb metals is in the treatment of arsenic (As)[43]. They demonstrated how it is possible to oxidize, and subsequently adsorb, As(III) to As(V) with TiO_2 acting as a photocatalyst by producing various reactive oxygen species such as the H+ ion, hydroxyl radical (OH^-), superoxide (O^{2-}), and hydrogen peroxide in the presence of UV-light. Going even further, single crystal nano TiO_2 particles have been developed to a point where nearly the entire face of the particle has a reactive surface, enabling one of the most efficient treatment mechanisms in the nanoproduct market[44]. Moreover, when targeting disinfection purposes, TiO_2 is also extremely effective, whether it be in the form of thin films [45]] as TiO_2 nanorods [46], doped with ferric iron[47], or combined with silver nanoparticles. These and many other studies report a killing efficiency of TiO_2 of at least 50%, but most often upwards of 80- 90%, meaning that this may not be capable of being the final disinfection agent for drinking water treatment purposes. However, if it were coupled with other treatment steps (i.e. advanced oxidation processes, membranes, etc.), it could act as an efficient cost-reducing measure to reduce chemical addition and inhibit biofouling of a membrane system. Similar to the use of iron oxides as a means to adsorb contaminants, and particularly heavy metals, zinc oxide nanoparticles are also used as a nanomaterial adsorbent.

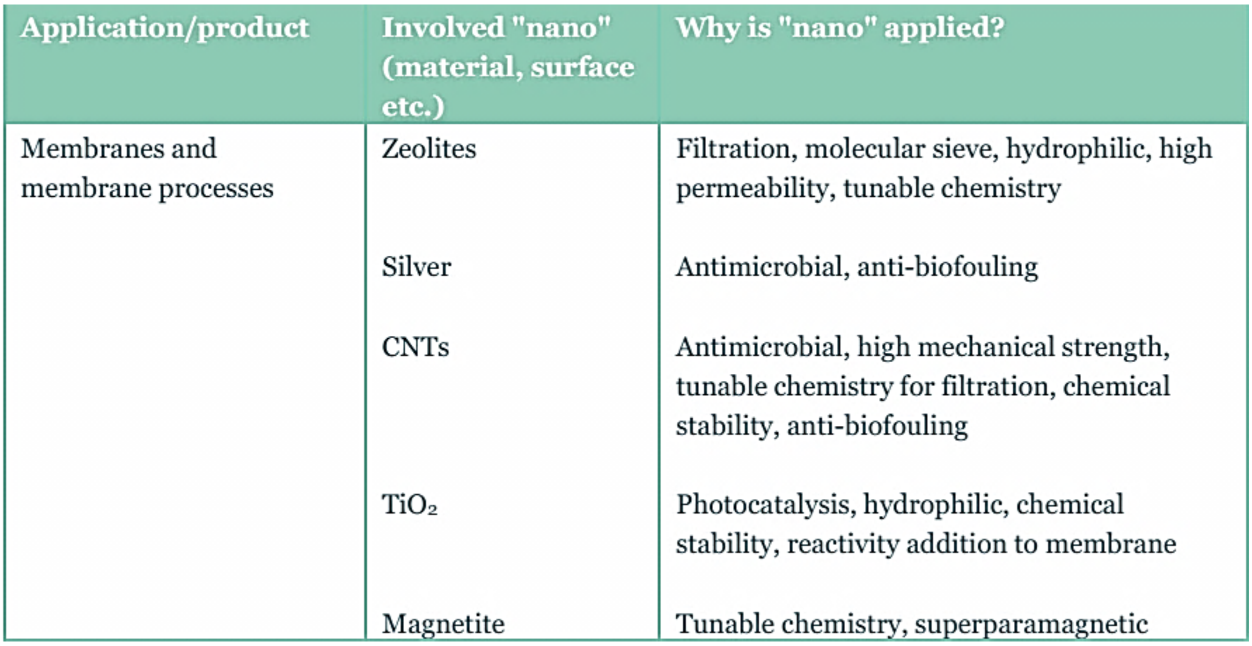
Table 1: Overview of the use of nanotechnology for water/wastewater treatment/purification



Application/product	Involved "nano" (material, surface etc.)	Why is "nano" applied?	Development stage
Pollutant removal by adsorption	CNTs (membranes, portable water filters), zeolites (membranes, desalination), metal-oxides and chitosan (powders in water treatment for adsorption or coagulation)	High surface area, high accessible adsorption sites, fine-tuning of compound to pollutant, easy to reuse	Primarily lab-scale and pilot-scale. Prototype commercial products.
Disinfection for drinking water or wastewater	Chitosan (membranes), Ag (membranes, portable water filters), TiO_2 and MgO (powders, thin films, membranes), CNTs (membranes, portable water filters)	Cell membrane damage, metal chelation in cells, reactive oxygen species (ROS) production, chemical stability	Primarily lab-scale and pilot-scale. Prototype commercial products.
Pollutant degradation by chemical reduction or photocatalysis	nZVI (flow-through columns, slurries), Au (membranes, slurries), TiO_2 (powders, thin films, membranes)	Catalytic reduction and photocatalysis not seen in bulk materials, unique quantum effects	Primarily lab-scale and pilot-scale

Similarly as with iron nanoparticles, zinc oxide does not adsorb metals well as a bulk commodity, but becomes quite effective when reduced to the nanoscale. Zinc oxide nanoparticles, in various forms, have been effective as an adsorbent for arsenic and other metals. Although the mechanism is not completely understood to date, zinc oxide nanoparticles' main advantage is their use as an antimicrobial agent against a wide range of bacteria, which has been proven in many situations[48,49]. One of the suggested mechanisms has been that since zinc oxide is known to have a high affinity to absorb UV-radiation, this will in turn lead to a photocatalytic production of hydrogen peroxide (H_2O_2), a well-known agent capable of destruction of microorganisms[48].

Table 2: Overview of the use of nanoproducts being incorporated into membrane technology



Application/product	Involved "nano" (material, surface etc.)	Why is "nano" applied?
Membranes and membrane processes	Zeolites	Filtration, molecular sieve, hydrophilic, high permeability, tunable chemistry
	Silver	Antimicrobial, anti-biofouling
	CNTs	Antimicrobial, high mechanical strength, tunable chemistry for filtration, chemical stability, anti-biofouling
	TiO_2	Photocatalysis, hydrophilic, chemical stability, reactivity addition to membrane
	Magnetite	Tunable chemistry, superparamagnetic

Another suggested mechanism for the antimicrobial power of zinc oxide is that zinc oxide nanoparticles are capable of penetrating the cell and consequently causing the unravelling of the cell membrane[50,51]. In the end, though, zinc in significant concentrations can be toxic to humans and aquatic life, and the Danish Ministry of the Environment recommends no more than 3-5 mg/L in drinking water at the tap . Magnesium based nanoparticles are primarily used in the disinfection of water. For example, Stoimenov et al.[52], demonstrated that magnesium oxide (MgO) can be extremely effective for treatment against various bacteria (e.g. *E. coli* and *B. megaterium*). This ability as a biocide comes from an unusually high surface area of MgO in nano-form and a unique crystalized structure that allows for many reactive surface sites. In addition to the very structure of the particles themselves, these MgO nanoparticles also possess a unique ability to uptake high amounts of halogens, and in particular chlorine gas, which further contributes to the biocidal activity[53]. However, this poses a problem as the halogen needs to be introduced to the particle. Therefore, although there is much interest in MgO as an antimicrobial agent in water, further progress in this as a treatment mechanism appears limited. Table 1 presents an overview of the nano-technologies identified for water and wastewater treatment and purification including nanomaterial involved, functionality, application areas and stage of development.

Additionally, it must be noted that many of these nanoproducts are actively being developed into membranes and membrane processes. Primarily, these are zeolites, silver, carbon nanotubes, TiO_2, and magnetite. The addition of these nanoproducts to membranes can aid in a wide variety of operational concerns, of note by acting as anti-biofouling agents, antimicrobial agents, or having tuneable chemistry to filter out particular compounds. A general overview of how and why these nanoproducts are used is summarized by Qu et al [54] as shown in in Table 2.

CONCLUSIONS

Nanotechnology for water and wastewater treatment is gaining momentum globally. The unique properties of nanomaterials and their convergence with current treatment technologies present great opportunities to revolutionize water and wastewater treatment. Although many nanotechnologies highlighted in this review are still in the laboratory research stage, some have made their way to pilot testing or even commercialization. Among them, three categories show most promise in full scale application in the near future based on their stages in research and development, commercial availability and cost of nanomaterials involved, and compatibility with the existing infrastructure: nanoadsorbents, nanotechnology enabled membranes, and nanophotocatalysts. All three categories have commercial products, although they have not been applied in large scale water or wastewater treatment. Several other water treatment nanotechnologies have found their niche applications in POU systems. The challenges faced by water/wastewater treatment nanotechnologies are important, but many of these challenges are perhaps only temporary, including technical hurdles, high cost, and potential environmental and human risk. To overcome these barriers, collaboration between research institutions, industry, government, and other stakeholders is essential. It is our belief that advancing nanotechnology by carefully steering its direction while avoiding unintended consequences can continuously provide robust solutions to our water/wastewater treatment challenges, both incremental and revolutionary.

Due to the increasing globalization and human needs, nanotechnology for water & waste water purification treatment is the first priority for the research. Nanotechnology is the best method to purify the water & waste water. This review paper describes various methods for potable water as well as waste water such as Nanotechnology applications for, reverse osmosis. Nanofiltration for Water and Waste water Treatment and Nanoparticles for water purification. The incorporation of nano materials present into existing water purification is a challenge also. Membrane processes such as RO, NF are becoming the standardized water purification techniques for public utilities and industry Thus nanotechnology holds a lot of promise in the remediation of groundwater and for this there is further scope in research and development.

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[13] Nanotechnology in Water Treatment Applications | Book Publisher: Caister Academic Press Editor: T. Eugene Cloete1, Michele de Kwaadsteniet1, Marelize Botes1 and J. Manuel López-Romero2 *1Faculty of Science, Stellenbosch University, South Africa; 2Faculty of Science, University of Malaga, Spain* Pages: viii + 196 ISBN: 978-1-904455-66

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