Nanotechnology: an approach for water purification -review

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Abstract. Clean water is the global need and need of life for all the human kinds. But the clean water resources are being contaminated in present time. Nanotechnology is an easy and practical approach to clean waste water by using different methods. Different types of bacteria, toxic chemicals like arsenic, mercury etc., and sediments can be removed by using nanotechnology. Nanomaterial based devices are being used for water purification. Nano filtration method has advantages over other conventional method as low pressure is required to pass the water through filters and these filters can be cleaned easily by back flushing. Smooth interior of carbon nanotubes make them convenient for the removal of almost all types of water contaminants. Because of larger surface area nanostructured materials have advantages over conventional micro structured materials.

1. Introduction
Water is the need of life for all the human kinds and now a days clean and pure drinking water is a big challenge as the quality of supplying fresh water is decreasing continuously[1,2]. So, there is need of such type of technology which can overcome this challenge and make available pure water for human kinds as pure water is essential for healthy life.

By improving water quality economy of any developed country can grow as techniques of water purification like chlorination, filtration and disinfection can give profit of 5- 10 dollars for 1 dollar investment [3]. In developing countries water treatment is a big issue due to poor maintenance ,irregular supply, contamination and dearth of chlorination[4–7]. Nanotechnology can help very well in this purpose to supply clean potable water for growing population. This technology refers to techniques using particles in nano range. These nanoparticles due to large surface area have unique physicochemical properties. Nanotechnology technique for water purification depends upon that at which stage of purification this technology has been applied. Different types of bacteria, toxic chemicals like arsenic, mercury etc., and sediments can be removed by using nanotechnology. Although risks are involved with nanomaterials because of high reactivity due to large surface area to volume ratio but in case of water purification done by nanotechnology no problem related to human health and environment have been reported.

In present era nanomaterial based devices are being used for water purification[8]. Nanomaterial based devices have advantages over other methods because of larger surface area[9]. These nanotechnology based chlorine free methods of water purification have advantage because chloramine or chlorine used in chlorine method produce carcinogenic byproducts[10]. Nanomembranes coated with photocatalytic titania are of great interest for water purification as titania has capability to degrade organic contaminants as well as destroy microorganisms[11,12] when irradiated by UV light.

These nanomembranes can also be coated by antimicrobial and photocatalytic material by applying atomic layer deposition method[13,14]. These nanomembranes may be useful for the development of water purification systems in developing countries. Nanostructured materials like magnetic nanoparticles, iron zeolite, carbon nanotubes can be engaged in water treatment for the removal of...
toxic metal ions like Hg(II), Pb(II), Cr(III), Cr(VI), Ni(II), Co(II), Cu(II), Cd(II), Ag(I), As(V) and As(III)]. These metal ions cause severe health issues[15]. Nanosized zero valent ions are used as adsorbents and also destruct persistent contaminants by catalyzing photochemical oxidation[16]. Because of extensive adsorption properties, carbon nanotubes and dendrimers are frequently being used for the development of advanced water systems[9,17].

2. Methods for Water Treatment
Adsortion is a very common techniques used for water treatment. Nanomaterials can be used as adsorbents for water treatment in various forms such as catalytic membranes, biomimetic membranes and thin film nanocomposite membrane etc. Carbon nanotubes(CNT) absorb chemicals more efficiently than activated carbon[18]. Organic compounds having functional groups like carboxylic, hydroxyl and amide has tendency to form hydrogen bond with CNT surface which donates electrons[19] and CNTs have high capacity to adsorb metal ions[20–22] that’s why good substitute of activated carbon. Nanoadsorbents are used in the form of either as powder or porous granules encumbered with nano-adsorbants.

2.1. Nanomembranes
Nanomembranes modified with nanofibers are being utilized for the removal of microsized particles[23]. These membranes are used in pretreatment method of reverse osmosis. Inorganic nanomembranes doped with titanium oxide have been reported for the degradation of chemicals specially chlorinated compounds[24,25]. Polymeric membranes immobilized with titanium oxide are very effective for the degradation of chlorinated compounds[26,27]. Polymeric membranes doped with nanosilver are applied to inhibit biofilm formation on the membrane surface[28,29] and to incapacitates viruses so can reduce bio fouling[30]. Because of unique properties nanocatalysts are very effective for the removal of contaminants from water shreiks. These catalysts are capable to degrade environmental contaminants halogenated pesticides, herbicides and nitrogenous aromatic compounds[31]. Biological nanoparticles show great potential for waste water treatment. MgO nanoparticles and Cellulose acetate (CA) fibers implanted with Ag nanoparticles have been reported as antibacterial against gram positive as well gram negative bacteria[32] so can also be used in water treatment.

2.2. Nanofiltration
In reference of drinking water production, contaminants can be removed from ground water as well as from surface water by using nanofiltration (NF) method. Softening is the major application of nanofiltration (NF) but also frequently used for the removal of micropollutants, and microorganisms. These are successfully installed in industries which proves their reliability. Nanofiltration are majorily installed in the drinking water industry. The reason for their success in water industries is that they work as softening membranes[33]. Softening of water is the major purposes of nanofiltration. Nanofiltration is also applied in the production unit where surface water is treated as nanofiltration (NF) can remove natural organic matter (NOM) very easily [Figure1]. Removal of natural organic matter (NOM) and color is more efficient in NF membranes than reverse osmosis membranes[34] . This process is shown in Figure 1.
3. Nanomaterials for Water Treatment

3.1. Metal Nanoparticles

3.1.1. Silver Nanoparticles
Silver nanoparticles are strong antibacterial agents and highly toxic to different bacteria, viruses and fungi[35–37]. This antimicrobial properties of silver nanoparticles make them useful as disinfectant for water. Now a days silver nanoparticles are successfully applied as disinfectant in water treatment. Although direct application of these silver nanoparticles reduce their proficiency in long-term use and may cause problems as they have tendency to aggregate in aqueous medium[38], still filter materials incorporated with silver nanoparticles are used as water disinfectant because of their antimicrobial properties and cost-effectiveness[39].

From last two decades, silver nanoparticles doped membranes or ceramic materials are frequently used for the treatment of household water due to their disinfecting and antifouling behavior[40]. For example ceramic filters prepared by clay and doped with silver nanoparticles are capable to enhance efficiency of removing E.coli. It was also observed that filters having high porosity have greater tendency to remove bacteria than filters with low porosity[41]. It was reported that silver nanoparticles upgraded the filter enactment and increased the removal rate of E.coli up to 97.8% and 100%[42].

3.1.2. Iron Nanoparticles.
Nano zero valent iron (nZVI) due to their small size and large surface area have excellent absorption and reducing properties[43]. These properties make these nano zero valent iron (nZVI )effective agents for the removal of large range of contaminants like halogenated, nitrogenous compounds, dyes, phenols, inorganic ions ,heavy metals and radioactive components[44–52]. When these nano zero valent iron (nZVI) and contaminants come in contact, oxidation-reduction reaction takes place which oxidize Fe$^{2+}$ to Fe$^{3+}$ so ferric hydroxide, Fe(OH)$_3$ will form and this Fe(OH)$_3$ will facilitates the removal of heavy toxic metals[53].
3.2 Metal Oxides Nanoparticles

3.2.1 Titanium oxide Nanoparticles (TiO₂ NPs)
Photocatalytic degradation method is the best method now a days for the removal of contaminants from waste water. Titanium oxide nanoparticles are using as an efficient catalyst because of their photocatalytic activity, cost effective and stability. These catalyst when come in the contact of contaminants, gradually oxidize them into low molecular weight products like CO₂, H₂O, NO₃⁻, Cl⁻ etc.[54–56]. Titanium oxide nanoparticles are selective degradation agents and used for the degradation of heavy metals, cyanides, polycyclic aromatic hydrocarbons, chlorinated organic compounds, dyes and phenols[57–64]. These nanoparticles are also effective antimicrobials against a wide range of gram-negative and gram-positive bacteria, fungi and viruses[65]. The coupling technology of titanium oxide nanoparticles, (TiO₂ NPs) with membrane such as polyvinylidene fluoride, polyethersulfone, polymethyl methacrylate, and polyamide-imide[66–71] is much more promising to resolve the recovery problem of titanium oxide nanoparticles (TiO₂ NPs). By this coupling, titanium oxide nanoparticles can easily be separated just using simple filtration method[72].

3.2.2 Zinc Oxide Nanoparticles (ZnO NPs)
ZnO NPs are also very efficient photocatalysis agents for waste water treatment due to their specific characteristics like band gap in the near-UV spectral region, and oxidizing power[73–75]. Biocompatibility of these nanoparticles make them suitable for waste water treatment[76].

3.2.3 Iron Oxides Nanoparticles
As iron oxides nanoparticles are simple and can easily be synthesized so these are frequently being used now a days for the removal of heavy metals. This is typical to recover nanosorbent materials from contaminated water because of their small size but magnetite and maghemite can be used as adsorbents because of their magnetic behavior. Because of magnetic behavior these iron oxide nanoparticles as a nanosorbants can be recovered from solution by applying external magnetic field. Therefore these nanoparticles are being magnificently working as nanosorbents for removing heavy metal ions from water[77–79].

3.3 Carbon Nanotubes (CNT)
Carbon nanomaterials (CNMs) are interesting adsorption agents because of their structural and electronic properties. Because of large surface area and selective nature for aromatics CNMs have advantages in wastewater treatment. CNTs, due to their structure are more efficiently being used than other carbon nanomaterials[80]. CNTs show specific adsorption capacity for cations, dyes and ethyl benzene etc.[22,81–84]. Functionalization of CNTs enhance their adsorption capacity by increasing surface area and dispersibility[85–88]. Nanocomposite adsorbent formed by the combination of CNTs having adsorption properties and iron oxide having magnetic properties, are capable in removing chromium from water.

3.4 Nanocomposites
Among nanomaterials nanocomposites are the most prominent materials now a days because of their magnetic properties and these properties make them easy to separate from the solution[89]. Nanofiltration membrane can be prepared by incorporating titanium oxide nanoparticles including the fabrication of co-polyamide network on a polyimide backing. Nanocomposites also have specific binding capacity through chelation, ion exchange and play active role in the different forms like polymer nanocomposites, carbon nanocomposites and metal oxide nanocomposites.

3.5 Dendrimers
Dendrimers are monodispersed nanosized distinct 3-D macromolecules having symmetric core, inner shell and outer shell. More complex nano-structured materials can be synthesized by using dendrimers
as nanoscale building blocks, e.g., dendrimer encapsulated NPs find use in materials engineering applications. Other materials can also be functionalize with dendrimers to enhance recovery rate of different metal ions from water. Dendrimers can also be used as chemical sensors and removal of heavy metals for water treatment. Dendrimers are water soluble ligands and this property make these useful for the absorption of toxic heavy metal ions in water purification[90]. Different nanomaterial can be represented by flow diagram given in Figure 2.

![Image](image_url)

Figure 2. Different Nanomaterials used in water purification

4. Nanofabrication
Nanomaterials can be fabricated by using basic two methods, one is bottom-up and other is top-down[91]. Bottom-up is a single step approach while top-down is a two step method. One of the popular one step approach is direct evaporation[92]. Chemical reaction method can also be used for the same purpose[93]. Two step method is commonly used for the fabrication process due to the low cost of material. In this two step method nanoparticles are dispersed in basefluid[94–101]. This process is most popular method for producing large scale of nanofluids[102].

5. Conclusion
Although risks are involved with nanomaterials because of high reactivity due to large surface area to volume ratio but in case of water purification done by nanotechnology no problem related to human health and environment have been reported. These nanotechnology based chlorine free methods of water purification have advantage because chloramine or chlorine used in chlorine method produce carcinogenic byproducts. By improving water quality economy of any developed country can grow, as techniques of water purification like chlorination, filtration and disinfection can give profit of 5-10 dollars for 1 dollar investment.

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