Nanotechnology for Water Treatment - A Review

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Abstract: New concepts and technologies are fast replacing the traditional methods of water treatment. Nano materials are well suited for water purification, disinfection and waste water treatment application as they have a very large specific surface area. Water is having a very essential role for vitality of life on earth and its treatment is very much required for day to day life. Nanotechnology is the study of manipulating matter on an atomic and molecular scale dealing with developing materials, devices, or other structures sized from 1 to 100 nanometers.We provide an overview of recent advances in nanotechnologies for water and wastewater treatment. The major applications of nanomaterials are critically reviewed based on their functions in unit operation processes.

Keywords: Carbon nanotubes, nanofiltration, nanotechnology, water treatment.

I. INTRODUCTION

Water is the most essential substance for all life on earth and a precious resource for human civilization. Providing clean and affordable water to meet human needs is a great challenge of this century. One of the most basic necessities is still remaining as a major global challenge even in the 21st century and reliable access to clean and affordable water is considered one of the most basic humanitarian goals. Some 780 million people still lack access to improved drinking water sources worldwide [1].

There is great concern worldwide regarding the viability of current practices of meeting the increasing demands of all water users in both the developed and developing countries. Hence there is a clear need for the development of innovative new technologies and materials for overcoming the challenges associated with the provision of supply of safe potable water. The increasingly stringent water quality standards, compounded by emerging contaminants, have brought new challenges to the existing water treatment and distribution systems. Although new approaches are continually being examined, these need to be lower in overall cost, durable and more effective than current options for the removal of contaminants from water. Nanotechnology holds great potential in advancing water and waste water treatment to improve the treatment efficiency . Nano filtration can effectively remove harmful ions of drinking water and therefore improve the drinking water environment and provide the protection of the resident's health.

Nanotechnology encompasses the creation and utilization of materials, devices and systems at the level of atoms and molecules, cutting across disciplines such as chemistry, physics, biology, engineering, and materials science [2].

Nano materials and nanostructures have nano scale dimensions that range from 1 to 100 nm, and often exhibit novel and significantly changed physical, chemical and biological properties. Within the category of treatment and remediation, nanotechnology has the potential to contribute to long-term water quality, availability, and sustainability of water resources [3].

Two vital properties make nanoparticles highly lucrative as sorbents. On a mass basis, they have much larger surface areas compared to macro particles. They can also be enhanced with various reactor groups to increase their chemical affinity towards target compounds [4].

Recent advances in nanotechnology offer many opportunities to develop next-generation water supply systems. Our current water treatment, distribution, and discharge practices, which heavily rely on conveyance and centralized systems, are no longer sustainable. Nanotechnology-enabled water and wastewater treatment promises to not only overcome major challenges faced by existing treatment technologies, but also to provide new treatment capabilities that could allow economic utilization of unconventional water sources to expand the water supply [4].

Nanotechnology is the design, characterization, production and applications of structures, devices and systems by controlling shape and size at nanometer scale. In recent years, a great deal of attention has been focused onto the applicability of nanostructured materials as adsorbents or catalysts in order to remove toxic and harmful substances from wastewater [5].

Nano materials are mainly categorised into various groups based on their physical and surface properties. The development of different nano materials like carbon nano tubes, nano sorbents, nano catalysts, zeolites, dendrimers, metal nano-adsorbents metallic nanoparticles, mixed oxide nanoparticle, polymer nano-adsorbents, nanofibers, nanoclays and nanostructured catalytic membranes has made it possible to remove toxic metals, and organic and inorganic solutes from water/wastewater and disinfect

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disease causing microbes. In this study, an attempt has been made to highlight the different technologies for efficient treatment of water using nanomaterials. Table 1 shows the application of nanotechnology in water and waste water treatment[6].

Table 1. Application of nanotechnology in water & waste water treatment

Sl.No	Type of Nanoparticle	Type of pollutants removed
1	Carbon nano tubes	Organic Contaminant
2	Nano Scale metal Oxide	Heavy metals Radionucleides
3	Nano catalyst PCB	Azodyes, Pesticides etc
4	Bioactive nanoparticle	Removal of Bacteria, fungi
5	Biomimetic membranes	Removing Salts

II.MECHANISMS OF REMOVING POLLUTANTS FROM WASTEWATER BY NANOMATERIALS:

A. Carbon nano tubes

Carbon nanotubes (CNTs) are cylinder-shaped macromolecules of which the walls of the tubes are made up of a hexagonal lattice of carbon atoms and they are capped at their ends by one half of a fullerene-like molecule [7]. CNTs have proved to be very effective in removing bacterial pathogens. CNTs have shown higher efficiency than activated carbon on adsorption of various organic chemicals(Pan and Xing, 2008). Its high adsorption capacity mainly stems from the large specific surface area. CNTs can be divided essentially into single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) based on the principle of hybridized carbon atom layers in the walls of CNTs.

Multi-walled carbon nanotubes (MWCNTs), pre-treated with nitric acid, have been used successfully for the sorption of different heavy metal ions, including Pb(II) (97.08 mg/g), Cu(II)(24.49 mg/g), and Cd(II) (10.86 mg/g) from an aqueous solution. These sorption capacities were three and four times higher than those of powder and granular activated carbon, respectively (Liet al. 2003). In addition, SWCNTs and MWCNTs were shown to have better Ni(II) sorption properties following their oxidation with NaClO. The treatment improved the surface properties of the CNTs, e.g., functional groups, total acidic sites and negatively charged carbons, thus resulting in them becoming more hydrophilic and therefore able to sorb more of the Ni(II) from the aqueous solution. Moreover, both SWCNTs and MWCNTs have been investigated for their ability to remove trihalomethanes from water. These compounds, which are recognized as potentially carcinogenic substances, are formed during the chlorination of drinking water. Both CNTs displayed high adsorption capacities for the respective THMs at 5 and 150C,which fluctuated very little in the pH range 3 to 7. Compared to activated carbon, the purified CNTs possessed two to three times higher adsorption capacities for CHCl3, which accounts for a major portion of THMs in chlorinated drinking water.

B. Nanofiltration

Nanofiltration (NF) is a new type of pressure driven membrane process and used between reverse osmosis and ultrafiltration membranes. The most different speciality of nanofiltration membranes is the higher rejection of multivalent ions than monovalent ions. Nanofiltration membranes are used in softening water, brackish water treatment, industrial wastewater treatment and reuse, product separation in the industry, salt recovery and recently desalination as two pass nanofiltration systems[8].Nanofiltration is a pressure-driven membrane separation process for removal of submicron particles with a molecular weight cut-off between 200 and 1,000 Daltons. (Nanofiltration (NF) membranes are considered low-pressure reverse osmosis (RO) membranes and have a pore size range of 0.001 to 0.005 µm. They have the added advantage of increased flux rates, recovery rates, and energy efficiency than RO membranes. It is a low pressure membrane process that separates materials in the 0.001-0.1 micrometer size. Nanofiltration membranes can retain95% of divalent ions and 40% of monovalent ions making them suitable for organic, microbiological, aqueous salt, color, and hardness removal [9]. Turbidity, microorganisms and inorganic ions such as Ca and Na can be removed using NF membranes. 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 pre-treatment in seawater desalination.

Nanofiltration membranes are being increasingly employed in a wide variety of applications including water and wastewater treatment owing to characteristics including selective separation of salts, good organic removal, and relatively low pressure requirements. It is also used in several industries for product purification and treatment (e.g. dairy, chemical, beverage, food, pharmaceutical, pulp and paper, textile, and oil and gas).

C. Nanoscale Zerovalent Iron

Iron nanoparticles are quite useful component for nano-remediation. Iron at the nanoscale was synthesized from Fe (II) and Fe (III), using borohydride as the reductant. The size of the nanoscale zero-valent iron particles are 10-100 nm in diameter. Nanoscale Zerovalent Iron is generally preferred for nano remediation because of large surface area of nanoparticles and more number of reactive sites

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than micro sized particles and it possess dual properties of adsorption and reduction.

D. Nanofiber membranes

Nanofiber membranes can remove micron-sized particles from aqueous phase at a high rejection rate without significant fouling (Ramakrishna et al., 2006). Thus they have been proposed to be used as pre treatment prior to ultrafiltration or reverse osmosis (RO). Electro spinning is a simple, efficient and inexpensive way to make ultra fine fibres using various materials [10]. The resulting nanofibers have high specific surface area and porosity and form nanofiber mats with complex pore structures.

Functional nano materials can be easily doped into the spinning solutions to fabricate nanoparticle impregnated nanofibers or formed in situ. The outstanding features and tunable properties make electrospun nanofibers an ideal platform for constructing multifunctional media/membrane filters by either directly using intrinsically multifunctional materials such as TiO2 or by introducing functional materials on the nanofibers.

E. Nanocomposite membranes

Polymer nanocomposites are materials in which nanoscopicin organic particles are dispersed in an organic polymermatrix in order to significantly improve the performance properties of the polymer. For instance, the layer orientation, polymer-silicate nano composites exhibit stiffness, strength and dimensional stability in two dimensions.

A significant number of studies on membrane nanotechnology have focused on creating synergism or multifunction by adding nano materials into polymeric or inorganic membranes.

Nanomaterials used for such applications include hydrophilic metal oxide nanoparticles (e.g., Al2O3, TiO2, and zeolite), antimicrobial nanoparticles (e.g., nano-Ag and CNTs),and (photo)catalytic nano materials (e.g., bi-metallic nanoparticles,TiO2).The main goal of adding hydrophilic metal oxide nano particlesis to reduce fouling by increasing the hydrophilicity of the membrane. The addition of metal oxide nano particles including alumina silica, zeolite and TiO2 to polymeric ultrafiltration membranes has been shown to increase membrane surface hydrophilicity, water permeability, or fouling resistance. These inorganic nanoparticles also help enhance the mechanical and thermal stability of polymeric membranes, reducing the negative impact of compaction and heat on membrane permeability [4].

III.RETENTION AND REUSE OF NANOMATERIALS

The retention and reuse of nanomaterials is a key aspect of nanotechnology enabled device design due to both cost and public health concerns. It can be usually achieved by applying a separation device or immobilizing nanomaterials in the treatment system. A promising separation process is membrane filtration which allows continuous operation with small footprint and chemical use. Ceramic membranes are more advantageous than polymeric membranes in photo catalytic orcatalytic ozonation applications as they are more resistant to UV and chemical oxidants. The suspended particles in the receiving water are detrimental to reactor membrane hybrid systems as they can be retained by the membrane and significantly reduce the reaction efficiency. Thus raw water pre treatment is usually required to reduce the turbidity. Nanomaterials also can be immobilized on various platforms such as resins and membranes to avoid further separation. However, current immobilization techniques usually result in significant loss of treatment efficiency. Research is needed to develop simple, low-cost methods to immobilize nanomaterials without significantly impacting its performance. For magnetic nanoparticles/nano composites, low-field magnetic separation is a possible energy-efficient option. Little is known about the release of nanomaterials from nano technology enabled devices. However, the potential release is expected to be largely dependent on the immobilization technique and the separation process employed. If no downstream separation is applied, nano materials coated on treatment system surfaces are more likely to be released in a relatively fast and complete manner, while nanomaterials embedded in a solid matrix will have minimum release until they are disposed of. For nanomaterials that release metalions, their dissolution needs to be carefully controlled (e.g., by coating or optimizing size and shape). Few techniques can detect nano materials in complex aqueous matrices and they are usually sophisticated, expensive and with many limitations [4].

IV. REMOVAL OF NANOPARTICLES AFTER WATER TREATMENT

The use of nanoparticles in environmental applications will invariably lead to the release of nanoparticles into the environment. Assessing their potential risks in the environment requires an understanding of their mobility, bioavailability, toxicity and persistence. The problems related to exposure of nanoparticles to aquatic and terrestrial life in water and soil is not fully known. Traditional methods for the removal of particulate matter during wastewater treatment include sedimentation and filtration. However, due to the small sizes of nanoparticles the sedimentation velocities are relatively low and significant sedimentation will not occur as long as there is no formation of larger aggregates. Common technologies such as flocculation might be inappropriate to remove nanoparticles from water, which points to the need of finding new solutions to the problem [5].

Research shows that NPs can be removed through coagulation if they are enmeshed by the coagulate floc as it

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sediments out of the water, in a process called sweep floc. Alternatively, coagulants added to the water may affect NP stability by producing positively charged hydrolytic species that neutralize negative surface charges on NPs, resulting in greater NP aggregation because electrostatic repulsion is mitigated .Removal of NPs by membrane filtration depends on membrane pore size, NP size, and NP stability—either aggregation or dissolution. Consistent removal of stabilized NPs will occur only if membrane pore sizes are smaller than NPs, such as the UF membrane. NP aggregate size is an important parameter for NP removal. Larger aggregates will be removed by settling floc during conventional treatment and by physical separation during advanced membrane filtration [11].Despite all of the many positive and transformative applications of nanoparticles, more research is needed to keep pace with the rapid expansion and proliferation of this technology on human health

V. CONCLUSION

In this paper we have made an effort to assess the suitability of nanotechnology for water and waste water treatment purposes. Nanotechnologies have made great improvements for handling water contamination problems and will clearly make further advancements in future. Nanotechnology based treatment has offered very effective, efficient, durable and eco friendly approaches. These methods are more cost-effective, less time and energy consuming with very less waste generations than conventional bulk materials based methods. The increasing trends of researches have made it clear that nanotechnology holds an immense potential to be developed into a very potent water treatment tool of the 21st century. Membrane processes such as RO, NF are becoming popular because they are flexible, scalable, modular and relatively easy to operate and maintain. Due to their extremely high potential in combination with the high specificity, nanoparticles can be developed into ideal candidates for water treatment and may contribute to solving future challenges in the area of water treatment technologies. The technology should be cost effective and friendly with ease in establishment and use. Future research needs to be done under more realistic conditions to assess the applicability and efficiency of different nanotechnologies as well as to validate nanomaterial enabled sensing technologies. Intensive research addressing the long term performance of water and wastewater treatment nanotechnologies is required. However certain precautions are to be taken to avoid any threat to human health or environment due to the nanoparticles.

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