Role of Nano-technology in Water and Waste-water Management

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ABSTRACT

Water is a very significant resource for us. But the wastewater resulting from, our day-to-day activities are becoming a hazard and hence its treatment has been an issue of prime concern these days. Its treatment is becoming a must in this industrial world because of the potentially harmful physical, chemical and biological constituents that such effluents carry. Nanoparticles have a great prospective to be used in water and wastewater treatment. Some of its characteristics such as a high surface area can be used to further efficiently in removing toxic metal ions, disease causing microbes, inorganic and organic solutes from water etc. Different classes of nano materials also have the authority to be efficient for water treatment like metal containing nanoparticles, carbonaceous nano materials and zeolites.Nanotechnology has led to various efficient ways for treatment of waste water in a more accurate and precise way on both small and large scale. The paper presents a review on the role of nanotechnology in water and wastewater treatment and includes recent developments in the said field.

Keywords:Nanotechnology, Nano-materials, water purification, water remediation, wastewater treatment, nano-membranes, adsorption.

I. INTRODUCTION

Water is a prime natural resource, a basic human need and a precious national treasure. Still there are 1 billion people in the developing countries which are not able to access the portable water and many people lack adequate sanitation. Due to the less amount of availability of the fresh water and rising demands of the portable water the world is facing great challenges in meeting these demands of the overgrowing population. Moreover, increasing pollution of the groundwater and the surface water due to agricultural, industrial and municipal activities of the people and hence ruined the water quality and reducing the supply of the fresh water. By increasing the demands of the water users there is a clear need for development of the new and innovative ways and technologies for the provision of the safe portable water.

Nanotechnology has been identified as a technology that could play an important role in resolving the problems involving the water purification and quality. The principal way nanotechnologies might help alleviate water problems is by solving the technical challenges by removing water contaminants, including pathogenic bacteria, viruses, harmful chemicals arsenic, mercury, pesticides, insecticides and salt pose etc. Major water pollutants include microbes (pathogens and viruses), nutrients (phosphates and nitrates), heavy metals and metalloids (arsenic, lead, mercury), organic chemicals (DDT, lubricants), oil, sediments and heat.

"Nano" is derived from the Greek word for dwarf. A nanometre is one billionth of a meter (10^{-9}) and might be represented by the length of ten hydrogen atoms lined up in a row. In nature, nanotechnology first emerged billions of years ago at the point where molecules began to arrange in complex forms and structures that launched life on earth. Through evolution, mutations and adaptations; plants were able to convert carbon dioxide using the energy from the visible range of sunlight to oxygen through a process known as "photosynthesis. This transformation is still taking place in tiny structures called "chloroplasts" composed of several Nano scale "thylakoid disks" that contain a green pigment (chlorophyll). Another example of a natural nanotechnology is "chemical catalysts" through "catalysts" or in bioscience called "enzymes". Enzymes are biomolecules that catalyse chemical reactions.

Nanotechnology has a great potential in enhancing water and wastewater treatment. It offers potential advantages like low cost, reuse and high efficient in removing and recovering the pollutants. Nanotechnology is the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale. Nano-materials are typically defined as the materials smaller than 100nm in at least one dimension.At Nano scale the material possess different size dependent properties such as volume ratio, reactivity, rapid dissolution and adsorption which are different from bulk material. These properties are used for treatment of water efficiently.

Most traditional techniques such as extraction, adsorption and chemical

Oxidation are generally effective but often very expensive. The ability to reduce toxic substances to safe levels effectively and at a reasonable cost is therefore very important. In this respect, nanotechnologies can play an important role. Due to their unique active surface area, nano-materials can offer a wide range of applications such as catalytic membranes, nanosorbents, bioactive nanoparticles and metal nanoparticles such as iron, silver, titanium oxides and many others.

In terms of wastewater treatment, nanotechnology is applicable in detection and removal of various pollutants. Heavy metal pollution poses as a serious threat to environment because it is toxic to living organisms, including humans, and not biodegradable.Various methods such as Photo catalysis, Nano filtration, Adsorption, and Electrochemical oxidation involve the use of TiO_2, ZnO, ceramic membranes, nanowire membranes, polymer membranes, carbon nanotubes, sub-micronnano-powder, metal (oxides), magnetic nanoparticles, nanostructure boron doped diamond are used to resolve or greatly diminish problems into living water quality in natural environment. Nanoparticles when used as adsorbents, nano-sizedzerovalent ions or nano filtration membranes cause pollutant removal/ separation from water whereas nanoparticles used as catalysts for chemical or photochemical oxidation effect the destruction of contaminants present. Scientists classified nanoscale materials that are being evaluated as functional materials for water purification into four classes namely, dendrimers, metalcontaining nanoparticles, zeolites and carbonaceous nano-materials.

II. NANO PROCESSES FOR WASTEWATER

2.1 Adsorption

Adsorption is the capability of all solid substances to attract to their surface molecules of gases or solutions in which they are in close contact. Solids that are used to adsorb gases or dissolved substances are called adsorbents, and the adsorbed molecules are usually referred to collectively as the adsorbate.Nanosorbents have very high and specific sorption capacity having wide application in water purification, remediation and treatment process. Commercialized nanosorbents are very few mainly from the U.S. and Asia but research is on going on in large numbers targeting various specific contaminants in water. Magnetic nanosorbents also helps in treating waste water and is proved very interesting especially for organic contaminants removal. Since most of the contaminants are not of magnetic nature filtration aids are needed to absorb which is generally followed by magnetic separation. The nanosorbents used for magnetic separation are prepared by coating magnetic nanoparticles with specific ligands presenting specific affinity. Different methods like magnetic forces, cleaning agents, ion exchangers and many more are used to remove nanosorbents from the site of treatment to avoid unnecessary toxicity. Regenerated nanosorbents are always cost effective and promoted more forcommercialisation. Few advancements and applications of nanosorbents are given below.

Sr. No.	Nanosorbent	Specialization/Treatment
1.	Carbon-based nanosorbents	Water containing nickel ions (Ni^{2+}). (high specific surface area, excellent chemical resistance, mechanical strength, and good adsorption capacity)
2.	CaptymerTM	Contaminants (perchlorate, nitrate, bromide and uranium) branched macromolecules forming globular micro particles
3.	Regenerable polymeric nanosorbent	Many organic and inorganic contaminants in wastewater
4.	Nanoclays	Hydrocarbons dyes and phosphorus
5.	Carbo-Iron	The activated carbon for sorption while the elementary iron is reactive and can reduce different contaminants
6.	Nano networks	Complex three-dimensional networks caused by the ion beam providing better efficiency

2.2 Nanocatalysts

Nanocatalysts are also widely used in water treatment as it increases the catalytic activity at the surface due its special characteristics of having higher surface area with shape dependent properties. Due to high surface to volume ratio and shape dependent properties Nanocatalysts are also widely used in water treatment as it increases the catalytic activity at the surface due its special characteristics of having higher surface area with shape dependent properties .It enhances the reactivity and degradation of contaminants. The commonly used catalytic nanoparticles are semiconductor materials, zero valence metal and bimetallic nanoparticles for degradation of environmental contaminants such as PCBs (polychlorinated biphenyls), azo dyes, halogenatedaliphatic,organochlorine pesticides, halogenated herbicides, and nitro aromatics. The catalytic activity has been proved on laboratory scale for various contaminants. Since hydrogen is used in making active catalyst in large scale by redox reactions, there is need in reducing its consumption and maintain hydrogen economy by directly making catalysts in metallic form.

Silver (Ag) nanocatalyst, AgCCA catalyst, N doped TiO and ZrO nanoparticles catalysts have been made which is highly efficient for degradation of microbial contaminants in water and are reusable as well. TiO AGS composite is very efficient for Cr (VI) remediation in waste water due to the modification done in TiO nanoparticles leading to absorption band shift from UV light activity to natural light degradation. Specific interactions between hydrogen and the Pd based nanoparticles were proved. Waste waters with specific contaminants like traces of halogenated organic compounds (HOCs) can be selectively biodegraded using advanced nanocatalyticactivitiesThe contaminants (HOCs) are first converted into organic compounds using nanosizedPd catalysts which are followed by its biodegradation in treatment plant. The nanocatalyst can be recycled back and reused due its property of having ferromagnetism which helps it to be easily separated.

The reductants for the reaction can be Hydrogen or Formic acid depending on the level of contamination.It has also been found that the nanocatalyst of silver and amidoxime fibres which is made by coordination interactions can be reactivated many times using simple tetrahydrofuran treatment and thus can be used efficiently for degradation of organic dyes.Palladium incorporated ZnO nanoparticles were found to be having very high abphotocatalytic activity for removal of from water which was studied through several analytical studies done using different concentrations of Pd in ZnO nanoparticles.

2.3 Nanomembranes

Membranes with nanofibres can remove micro size particles from aqueous phase with a high elimination rate without considerable fouling. Such membranes are used are pre treatment methods used proceeding to ultra filtration and reverse osmosis. Nanofiltration members are characterized by a unique charge based repulsion mechanism allowing the separation of the various ions.

RO can remove the smallest of solute molecules, in the range of 0.0001 micron in diameter and smaller, nanofiltration (NF) removes molecules in the 0.001 micron range. It refers to a membrane process that rejects solutes approximately 1 nanometer (10 angstroms) in size with molecular weights above 200. Because they feature pore sizes larger than RO membranes, NF membranes remove organic compounds and selected salts at lower pressures than RO systems. It is also capable of removing bacteria and viruses as well as organicrelated color without generating undesirable chlorinated hydrocarbons and trihalomethanes.Nanofiltration is used to remove pesticides and other organic contaminants from surface and ground waters to help insure the safety of public drinking water supplies. Sometimes referred to as "membrane softening," NF is an attractive alternative to lime softening orzeolite softening technologies and since NF operates on lower pressure than RO, energy costs are lower than for a comparable RO treatment system. As such, nanofiltration is suited especially to treatment of well water or water from surface supplies such as rivers or lakes.

2.4 Nanostructured Catalytic Membranes (NCMS)

Nanostructured catalytic membranes are widely used for water contamination treatment. It offers several advantages like high uniformity of catalytic sites, capability of optimisation, limiting contact time of catalyst, allowing sequential reactions and ease in industrial scale up. Nano-filtration membranes are already widely applied to remove dissolved salts and micro-pollutants, soften water and treat wastewater. The membranes act as a physical barrier, capturing particles and microorganisms bigger than their pores, and selectively rejecting substances. Nanotechnology is expected to further improve membrane technology and also drive down the prohibitively high costs of desalination getting fresh water from salty water. Several functions which include decomposition of organic pollutants, inactivation of microorganisms, anti-bio fouling action, and physical separation of water contaminants are performed by nanostructured TiO2 films and membranes under UV and visible-light irradiation. The N-doped "nut-like" ZnO nanostructured material forming multifunctional membrane is very efficient in removing water contaminants by enhancing photo degradation activity under visible light irradiation. It also showed antibacterial activity and helped in producing clean water with constant high flux benefiting the water purification field. Various studies have been done regarding immobilisation of metallic nanoparticles in membrane (such as cellulose acetate, polyvinylidene fluoride (PVDF), polysulfone, chitosan, etc.) for effective degradation and dechlorination of toxic contaminants which offers several advantages like high reactivity, organic partitioning, prevention of nanoparticles, lack of agglomeration and reduction of surface passivation.Nanocomposites films have been prepared from polyetherimide and palladium acetate and specific interactions between hydrogen and the Pd based nanoparticles have been studied providing the efficiency in water treatment.

2.5 Nanofibers

Nanofiber technology in combination with biological removal of toxic xenobiotics is the advanced method in industrial wastewater treatment process. Microbial biofilm formation can be greatly supported using nanofiber structures, and the whole system provides stable and accelerated biodegradation. Nanofiber carriers are examined on various parameters like cleaning efficiency of toxic compounds, stability of carrier and nanofiber layer, rate of carrier in growths by relevant microorganisms, disintegration of nanofibers and sorption properties. Each biomass carrier must meet the basic parameters (microorganism colonization ability, chemical and physical stability, surface morphology, maximum specific surface).The exceptional properties of nanofiber carriers are primarily the large specific surface, high porosity and small pore size. ElectrospunPolyacrylonitrilenanofiber mats are being used for heavy metal ion removal because of tremendous potential as a heterogeneous adsorbent for metal ions.

Depending on the type of polymer, nanofibers are durable, easily moldable and chemical resistant. The principal advantage of nanofiber materials is their comparability with the dimensions of micro-organisms, the surface morphology and biocompatibility, which allows for faster colonization of the nanofiber surface by the microorganisms.An important advantage of the technology is the possibility of a bacterial biofilm build-up not only on the surface of the carrier but also closer to its centre (inside the carrier), where the bacteria are much more protected against the toxic effects of the surrounding environment and shear forces during hydraulic mixing. In addition, penetration of substrate and oxygen to the microorganisms is also possible. High specific surface of the nanofiber layer allows to the bacteria great adhesiveness and as a result it simplifies the immobilization of microorganisms, especially in the initial stages of colonization of the surface carriers and also even during difficult emergency conditions (reducing the required regeneration time). After a longer period of colonization the microbial biomass grows naturally on the places without the nanofibers thus making the process of wastewater treatment more efficient. Fe-Grown Carbon Nanofibers are being used for removal of Arsenic (V) in wastewater.

Type of Nanoparticle	Type of pollutants removed
Carbon nano tubes	Organic Contaminant
Nano Scale metal Oxide	Heavy metals Radionucleides
Nano catalyst	PCB, Azodyes,Pesticides etc
Nano Structured catalytic	Decomposition of organic pollutant inactivation of micro organisms
Bioactive nanoparticle	Removal of Bacteria, fungi
Biomimetic membranes	Removing Salts

III. EFFECTS OF NANOTECHNOLOGY

3.1 Positive Effects of Nanotechnology

- Cost saving on materials: An alternative energy method will decrease the price by novel developments in nanotechnology.
- Less waste on raw materials: Large sample testing will be done on a smaller scale and simultaneously use of raw materials will become more efficiency.
- Nanoscale chemical reagents (or catalysts) increase the reaction rate and other efficiency of chemical reactions.
- Environmental monitoring and protection: Utilizing advanced nanotechnology.
- Biological applications: Developing ultra-small probes on planetary surfaces for agricultural applications and control of soil, air, and water contamination.
- Biomedical applications: This includes the medical diagnostic and treatments.
- Cleaner, more efficient industrial processes.
- Improved ability to detect and eliminate pollution by improving air, water and soil quality.
- High precision manufacturing by reducing amount of waste.
- Clean abundant power via more efficient solar cells.
- Removal of greenhouse gases and other pollutants from the atmosphere.
- Decreased need for large industrial plant.
- Remediating environmental damages.

3.2 Potential Environmental Effects

- There are few considerations of potential risks need to be considered using nanoparticles:
- The major problem of nanomaterials is the nanoparticle analysis method, as nanotechnology improves, new and novel nanomaterials are gradually developed. However, the materials vary by shape and size which are important factors in determining the toxicity. Lack of information and methods of characterizing nanomaterials make existing technology extremely difficult to detect the nanoparticles in air for environmental protection.
- Also, information of the chemical structure is a critical factor to determine how toxic material is, and minor changes of chemical function group could drastically change its properties.
- Full risk assessment of the safety on human health and environmental impact need to be evaluated at all stages of nanotechnology. The risk assessment should include the exposure risk and its probability of exposure, toxicological analysis, transport risk, persistence risk, transformation risk and ability to recycle.
- Life cycle risk assessment is another factor that can be used to predict the environmental impacts.
- Good experimental design in advance of manufacturing a nanotechnology based product can reduce the material waste.
- High energy requirements for synthesizing nanoparticles causing high energy demand.
- Dissemination of toxic, persistent nano substances originating environmental harm.
- Lower recovery and recycling rates.
- Environmental implications of other life cycle stages also not clear.
- Lack of trained engineers and workers causing further concerns.

IV.CONCLUSION

Nanotechnology for water and waste water treatment is increasing day by day. The exclusive properties of nanomaterials show great opportunities for water and wastewater treatment. Although nanotechnology enabled water/wastewater treatment processes have shown great promise in laboratory studies, their readiness for commercialization varies widely. Some are already on the market, while others require significant research before they can be considered for full scale applications. Their future development and commercialization face a variety of challenges including technical hurdles, cost-effectiveness, and potential environmental and human risk. There is a significant need for the novel advanced water technologies in particular to ensure high quality of drinking water, eliminate pollutants and intensify industrial products processes by the use of flexibility adjustable water treatment systems. These nano-engineered materials are compatible with the existing treatment technologies and can be intergrated with the conventional ones.However there are still several drawbacks to be negotiated.

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