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Applications of Nanotechnology in Wastewater Treatment

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Abstract:

Waste water treatment issues have been a growing problems these days. Its treatment is becoming must in this Industrial world. Nanoparticles have a great potential to be used in waste water treatment. Some of the unique characteristics of it having high surface area can be used efficiently for removing toxic metal ions, disease causing microbes, inorganic and organic solutes from water. The different classes of nanomaterials also have the authority to be efficient for water treatment like metal-containing nanoparticles, carbonaceous nanomaterials and zeolites. The review includes recent development in nanotechnology for water and wastewater treatment. The paper covers nanomaterials that enables the applications, advantages and limitations as compared to existing processes. Nanotechnology has led to various efficient ways for treatment of waste water in a more precise and accurate way on both small and large scale.

Keywords: Nanotechnology, Nanomaterials, Sorbents, Wastewater, Nanofibers.

I. INTRODUCTION

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., altogether, instead of dumping from one resource to another, as environmental issues have global impact, destroying every component of atmosphere at an alarming rate. The presence in the environment of large quantities of toxic metals such as mercury, lead, cadmium, zinc or others, poses serious health risks to humans, and this threat puts the scientific community under pressure to develop new methods to detect and eliminate toxic contaminants from wastewaters in efficient and economically viable ways. Utilizing nanotechnology for wastewater treatment would certainly help the human being, our environment as well as industry too as it has shown amazing results in every fields [3].

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[1]. Due to their unique active surface area, nanomaterials 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.

"**Nano**" is derived from the Greek word for dwarf. A nanometer 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.

II. NANO PROCESSES FOR WASTEWATER

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, Nanofiltration, Adsorption, and Electrochemical oxidation involve the use of TiO_2, ZnO, ceramic membranes, nanowire membranes, polymer membranes, carbon nanotubes, submicron nanopowder, metal (oxides), magnetic nanoparticles, nanostructure boron doped diamond are used to resolve or greatly diminish problems involving water quality in natural environment. Nanoparticles when used as adsorbents, nanosized zerovalent ions or nanofiltration 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, metal-containing nanoparticles, zeolites and carbonaceous nanomaterials.

A. Nanosorbents

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 [6]. 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 for commercialization. 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

Table 1. Different Specialization of Nanosorbent

B. 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 .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, halogenated aliphatic, organochlorine pesticides, halogenated herbicides, and nitro aromatics[6]. 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 [6].

Silver (Ag) nanocatalyst, AgCCA catalyst, N-doped TiO_2 and ZrO_2 nanoparticles catalysts have been made which is highly efficient for degradation of microbial contaminants in water and are reusable as well. TiO_2-AGS composite is very efficient for Cr (VI) remediation in waste water due to the modification done in TiO_2 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 nanocatalytic activities [8]. The contaminants (HOCs) are first converted into organic compounds using nano-sized Pd 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 (Hildebrand et al., 2008)13.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 E.coli from water which was studied through several analytical studies done using different concentrations of Pd in ZnO nanoparticles.

C. 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 optimization, limiting contact time of catalyst, allowing sequential reactions and ease in industrial scale up. Nanofiltration membranes are already widely applied to remove dissolved salts and micro-pollutants, soften water and treat wastewater[6]. The membranes act as a physical barrier, capturing particles and micro-organisms 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 TiO_2 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 immobilization 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 [5].

Nanocomposites films have been prepared from polyetherimide and palladium acetate and specific interactions between hydrogen and the Pd based nanoparticles have been studied proving the efficiency in water treatment. The metal nanoparticles were generated within the matrix by annealing the precursor film under different conditions using both in situ and ex situ method. This provides opportunities to design materials having tunable properties.

With the advancement in nanotechnology several novel nanostructured catalytic membranes has been with increased permeability, selectivity, and resistance to fouling. The techniques include bottom-up approaches and hybrid processes for enabling its multi functionality [6].

D. Catalytic Wet Air Oxidation using Nanoparticles

A great challenge in nanotechnology is to design highly selective catalysts comprising of an active site with the correct ensemble of metal atoms and other active components. The main advantage of nanocatalysts prepared in organic functional polymers is the easy tailoring via variation of the polymer nature. Such catalysts are characterized by high activity-selectivity-stability. Here we report the synthesis of Pt, Pd, Ru nanoparticles impregnated in hyper cross linked polystyrene matrix as efficient catalysts for CWAO of phenol. CWAO treatment of phenol compounds realized on the base of hyper cross linked polystyrene impregnated with platinum nanoparticles leads to high phenol conversion. Catalytic wet air oxidation of Oxalic Acid using Platinum catalysts in Bubble Column Reactor provides an efficient method of combustion at very low temperature as compared to thermal incineration [9].

E. 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 [5].

Nanofiber carriers are examined on various parameters like cleaning efficiency of toxic compounds, stability of carrier and nanofiber layer, rate of carrier ingrowths 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. Electrospun Polyacrylonitrile nanofiber mats are being used for heavy metal ion removal because of tremendous potential as a heterogeneous adsorbent for metal ions [4].

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 [4].

An important advantage of the technology is the possibility of a bacterial biofilm buildup not only on the surface of the carrier but also closer to its center (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.

F. Membrane Filtration Technology

Nanofiltration is a liquid separation membrane technology positioned between reverse osmosis (RO) and ultrafiltration. While 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[5]. 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 organic-related color without generating undesirable chlorinated hydrocarbons and tri-halomethanes.

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 or zeolite 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[5].

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 photocatalytic or catalytic 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[9]. Thus raw water pretreatment 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/nanocomposites, low field magnetic separation is a possible energy efficient option [9].

Little is known about the release of nanomaterials from nanotechnology 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, nanomaterials 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 metal ions, their dissolution needs to be carefully controlled (e.g., by coating or optimizing size and shape). The detection of nanomaterial release is a major technical hurdle for risk assessment and remains challenging. Few techniques can detect nanomaterials in complex aqueous matrices and they are usually sophisticated, expensive and with many limitations[9].

IV. Effects Of Nanotechnology

Nanotechnology has positive as well as negative effects [8].

A. *Positive Effects Of Nanotechnology*

- Cost saving on materials: An alternative energy method such as hybrid automobiles 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, a detector was made to detect a nuclear leak faster and more accurate at the Fukushima Daiichi Nuclear Power Plant. Which is one of the best radiation detector in Washington and can sense the faintest amount of radiation.
- 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.

B. *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.

CONCLUSION

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 are two major research needs for full scale applications of nanotechnology in water/wastewater treatment. First, the performance of various nanotechnologies in treating real natural and waste waters needs to be tested. Future studies need 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. Secondly, the long-term efficacy of these nanotechnologies is largely unknown as most lab studies were conducted for relatively short period of time. Research addressing the long term performance of water and wastewater treatment nanotechnologies is in great need. As a result, side-by-side comparison of nanotechnology enabled systems and existing technologies is challenging.

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