



Nanotechnology in Waste Water Treatment

Science

Prem Lata Meena	Dept. of Polymer Science, Bhaskaracharya College of Applied Sciences, University of Delhi, Sec-2, Dwarka, New Delhi, India- 110075
Vinay	Dept. of Polymer Science, Bhaskaracharya College of Applied Sciences, University of Delhi, Sec-2, Dwarka, New Delhi, India- 110075
Tanmay Tyagi	Dept. of Polymer Science, Bhaskaracharya College of Applied Sciences, University of Delhi, Sec-2, Dwarka, New Delhi, India- 110075

ABSTRACT

Worldwide, water supply struggles to keep up with the fast-growing demand, which is intensified by various factors such as population growth, global climate change, urbanization, industrial growth, water quality deterioration etc. Providing clean and affordable water to meet human needs is one of the current challenges of the 21st century. Nanotechnology's application in waste water treatment can make the process more efficient and also increase the water supply via safe use of unconventional water sources. Due to nanoparticles' high reactivity, high specific area, size-dependent properties and a high degree of functionalization, they are suitable for wastewater treatment and water purification applications. The present article relies on the nanotechnology application to provide and meet the demands of safe water.

KEYWORDS:

Nanoparticles, waste water

1. Introduction

About 2.7 per cent of the total water available on the earth is fresh water of which about 75.2 per cent lies frozen in polar regions and another 22.6 per cent is present as ground water. The rest is available in lakes, rivers, atmosphere, moisture, soil and vegetation [1]. Water is one of the most important renewable natural resources for supporting life. India's increasing population and all-round development, has also increased the utilization of water at a fast pace. The water demand in the year 2000 was 634 km³ and it is likely to be 1093 km³ by the year 2025 [2]. Most of the water sources like ponds, lakes, oceans etc. have been polluted due to increasing industrial growth, urbanization and other man-made problems. Major water sources receive high content of waste such as sewage, domestic, agricultural and industrial effluent etc., which contain substances ranging from simple nutrients to highly toxic chemicals like heavy metals, etc. In India, all the 14 major rivers which are the lifelines of country have become polluted.

Water consisting a unique chemical character with properties of dissolving and carrying in suspension a huge variety of chemicals i.e. organic and inorganic respectively, and it get contaminated easily [3]. Organic and inorganic chemicals include volatile organic compounds, waste from trees, fuels, plants etc. and ammonia, discarded cosmetics, waste from industries etc. respectively. The water which travels through the fields is often contaminated by fertilizers and generally contains all forms of waste. This wastewater reaches our sources of water and hence endangers the plants, animals and humans that use it [4]. Hence, there is extremely high need to treat this wastewater as the pressures are three-fold. Firstly, water scarcity both in terms of quality and quantity leads to a shortage of supply. Secondly, Exponential increasing demand as India's population, food demands, industrial requirements increase with development and economic activities ahead. Thirdly, the loss of aquatic ecosystems which will ultimately result in dry river and lakebeds [5].

The conventional ways of treating polluted water are industrial treatment, denitrification, ozone waste water treatment and septic tanks [4,5]. Disadvantages of these kinds of conventional techniques is that they are unable to remove the heavy metal and pathogenic microbes. The presence of toxic metals such as mercury, lead, cadmium, zinc or others in the environment, poses serious health risks to humans and the ecosystem. This threat forces the scientific community to develop new methods to detect and eliminate toxic contaminants from wastewaters in efficiently and economically. Hence, the separation at nano-scale comes. Nanotechnologies might help to eliminate water problems by solving the technical challenges by removing water contaminants, including pathogenic bacteria, viruses, harmful chemicals, arsenic, mercury, pesticides, insecticides and salt pose etc., altogether. 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 field [2]. Hence, nanotechnology can play an important role. The chapter deals with various aspects of using nanoscience in treatment of wastewater.

2. Nanotechnology

Nanotechnology deals with a phenomenon or material on a nanometer scale. Hence, defined as the study, design, characterization, production and application of structures, products, devices and systems in the nanometer range [6]. Even though numerous techniques are used in fabrication of different nanomaterials, they can be generalized in two main categories based on our starting point of production.

a) Category-1: "Top-to-Down" - This approach consists of application of considerably ultrafine grinders, lasers and vaporization followed by cooling.

b) Category-2: "Bottom-to-Up"- This approach is preferred to synthesize nanostructures by forming new arrangement of molecules to form other complex structures with new and useful characteristics [7]. In this chapter, nanofiltration membranes, nano adsorbents, and nanoparticles are discussed.

3. Nanofiltration- a membranous technique

The removal of particulate matter from water by forcing it through a porous semi-permeable media under pressure is known as filtration. Nanofiltration membranes are widely used in wastewater treatment. It separates materials in the size range of 0.001-0.1µm and operated at low pressure level. Their characteristic is in between of reverse osmosis and ultra-filtration membranes and have pore sizes between 0.2-4 nm [6,8] and reported to remove turbidity, microorganisms and inorganic ions such as calcium and sodium ions. It is widely used for softening of groundwater (reduction in water hardness), removal of trace pollutants from surface water, dissolved organic matter and wastewater treatment and for pretreatment in seawater desalination [6].

Like other filtration membranes such as RO, most NF membranes are charged. Hence, electrostatic interactions also influence the transport and selective rejection behaviour of NF membranes. The salts which are filtered easily include bromide and iodide ions, although in general, polyvalent ions may be more easily retained than monovalent ions.

3.1 Comparison between RO and NF

When compared to RO, NF has slightly lower capital cost, significantly lower operational cost due to lower operating pressures and can be operated at a higher water recovery, which means a smaller waste concentrate stream, while achieving comparable bromide and

iodide removals but on the contrary they require extensive pre-treatment, medium to high energy consumption, and is susceptible to scaling and brine disposal difficulties [8].

3.2 Polymeric Membranes are best suited NFs

Polymeric membranes are the best suited because of following reasons:

(a) No chemical effect; (b) Little swelling, membrane may be compatible for short-term use; (c) Extensive swelling and slow dissolution of membranes; (d) Complete dissolution or disintegration of membranes; (e) Relaxation of polymer chains due to plasticization in solvent resulting in swelling with subsequent pore size reduction [10].

The various polymeric nanomembranes which is used in Nano-filtration of wastewater are

(a) Poly(vinyl alcohol) based (PVA)

PVA has good physical and chemical properties as a membrane material and has been widely used for the preparation of several kinds of membranes specifically, for the formation of pervaporation membranes to separate water-alcohol mixtures due to its good hydrophilicity. Ionomers, such as sodium alginate and chitosan, were considered to improve solute rejection without a decrease in the flux of PVA membranes [9].

b) Polyacrylonitrile (PAN)

PAN provides resistance to a wide range of solvents; however, formation of homogeneous membranes is not feasible with either of them. Hence, a composite NF membrane with PAN-UF membrane as a substrate with a thin layer of chitosan is used. Additionally, a hydrophilic surface of these membranes would be desirable for protein separation [10].

Others are Polyamides, cellulose acetate and Polyethylene based membranes.

4. Nano-adsorbents

Adsorption is one of the most effective processes of advanced wastewater treatment, which is employed to reduce hazardous organic, inorganic and toxic wastes from water. Phenolic compounds are hazardous wastes, which are released into the aquatic environment by industries which are removed by the use of activated carbon [11].

4.1 Types of adsorbents

On the basis of origin adsorbents can be classified into two categories i.e. natural adsorbents and synthetic adsorbents. Adsorbents like charcoal, clays, clay minerals, zeolites, and ores, fall under the category of natural adsorbents and are relatively cheap, abundant in supply and have significant potential for modification and ultimately enhancement of their adsorption capabilities. Synthetic adsorbents are prepared from agricultural products and wastes, house hold wastes, industrial wastes, sewage sludge and polymeric adsorbents. Each adsorbent has its own characteristics such as porosity, pore structure and nature of its adsorbing surfaces.

4.2 Heavy metal removal from wastewater

Among all water contaminations, heavy metal ions, such as Pb²⁺, Cd²⁺, Zn²⁺, Ni²⁺ and Hg²⁺, have high toxic and nonbiodegradable properties, and can cause severe health problems in animals and human beings. Heavy metal ions can be removed from wastewater by the use of traditional sorbents but their low sorption capacities and efficiencies serves as a limitation. Therefore sorbents such as carbon based nanomaterials and graphenes are used.

Such sorbents are used due to their nontoxicity and high sorption capacities. Activated carbon is used as a sorbent but it is difficult to remove heavy metals at ppb levels. This problem is rectified by the use of carbon nanotubes, fullerene, and graphene as nanosorbents [13].

4.3 Organic Waste removal

a. Adsorption of dyes

The textile, pulp and paper industries are reported to utilize large quantities of a number of dyes, and may be found in wastewaters generating considerable amounts of colored wastewaters, toxic and even carcinogenic hazards to aquatic living organisms. Activated rice husk was used as cheap adsorbent for color removal from wastewater.

Hamdaoui reported that the maximum adsorption of basic dye, methylene blue, onto cedar sawdust and crushed brick was 60 and 40 mg L⁻¹, respectively.

b. Adsorption of phenols

The major sources of phenolic wastes are steel mills, petroleum refineries, pharmaceuticals, petrochemical, coke oven plants, paints, coal gas, synthetic resins, plywood industries and mine discharge. One of the most investigated liquid-phase application of carbon adsorbents is the removal of aqueous phenol and its compounds. Some of the other adsorbents used for this purpose are carbonaceous materials, activated carbon (AC), bagasse ash (BA) and wood charcoal (WC). A research found out the removal efficiencies of 98%, 90% and 90% respectively for phenol-AC, phenol-WC and phenol-BA. It was also indicated that the removal efficiency of phenol slightly increased when the pH of adsorption system decreased [12].

c. Adsorption of pesticides and herbicides

After their application to get rid of the pests, pesticide residues are removed from substrates by rinsing with water which leads to the formation of toxic wastewater which can lead to adverse effects on people, pets, livestock and wildlife. Pesticides' and herbicides' toxicity, carcinogenicity and mutagenicity are the main reasons why they are harmful to life [29]. Organic pollutants can be efficiently adsorbed by the use of cyclodextrin-based polymers (CDPs), the advantages of which are specific affinity, low cost and simple design. CDPs can be manufactured by using cyclodextrin (CD) as a complex molecule and a polyfunctional substance (e.g., epichlorohydrin (EPI)) as a cross-linking agent.

5. Nanoparticles

Nanomaterials are fast emerging as potent candidates for water treatment in place of conventional technologies [6]. The four major classes of nano-scale materials which have been evaluated as most functional materials for enhancement of water quality are as follows-

a) Dendrimers, b) Metals, c) Zeolites and d) carbonaceous.

5.1 Dendrimer

Dendrimer is a class of polymer which includes random hyper branched polymers, dendrigraft polymers, dendrons and dendrimers. They are symmetrical and spherical structurally, with a relatively dense shell which is composed of a core, branching sites and terminal groups that usually form a well-defined surface. They are available in different shapes such as cones, spheres, and disc-like, generally in the size range of 2 to 20 nm. It can be used as high capacity, and recyclable water soluble ligands for toxic metal ions and recyclable unimolecular micelles for recovering organic solutes from water.

e.g. Poly (amidoamine) dendrimer (PAMAM) based silver complexes and nanocomposites which is used as antimicrobial agents in vitro. The protected silver and silver compounds showed high antimicrobial activity against *S. aureus*, *P. aeruginosa* and *E. coli* without the loss of solubility [16].

5.2 Metals and their oxides

Metal nanoparticles include nano-sized silver, gold, palladium etc. particles. E.g. Engineered Nano-silver forms with size ranging from 10-200nm comprises of colloidal silver, nano-silver powder, spun silver, and polymeric silver. They work efficiently in wastewater treatment because of their high surface reactivity and strong antimicrobial properties. They also find applications in medicine, water purification, and antimicrobial uses. They are used for a wide variety of commercial products [16].

Metal oxide nanomaterials have important physio-chemical and biological properties which make them particularly attractive for the treatment of waste water. Due to their large surface areas and their size, shape and dimension dependent catalytic properties, considerable efforts have driven to explore their applications such as catalysis, adsorption and membrane separations. In addition, it can be functionalized with various chemical groups to increase their affinity towards many interesting compounds [15].

5.3 Zeolites

Zeolite nanoparticles can be manufactured by laser-induced fragmentation of zeolite LTA microparticles using a pulsed laser or by hydrothermal activation of fly ash. It can be used as an ion exchange

media and effective sorbents for removal of metal ions. Zeolites have been reportedly used in the removal of heavy metals such as Cr(III), Ni(II), Zn(II), Cu(II) and Cd(II) from metal electroplating and acid mine wastewaters [16]. Natural Zeolite can be used to filter and purify swimming pools, town water supplies, sewerage effluent, biological wetlands, industrial and mining waste-water and aquaculture ponds.

5.4 Carboneous and Carbon nano tubes

Carbon nanotubes (CNTs) are a new fascinating member in the carbon family. They have been a locus of new researches because of their unique one-dimensional structures, excellent electrical and mechanical properties. On the basis of number of layers they can be classified broadly into single-walled CNTs (SWCNTs) and multi-walled CNTs (MWCNTs). They find applications in manufacture of composites and electronic devices but due to their high thermal and chemical stability they have started to find application as catalyst carries. Removal of various toxic wastes such as lead, cadmium and organic 1,2-DCB has become more efficient with the use of CNTs [17]. Although RO, NF, MF, UF and other membranes have been used efficiently to tackle the fresh water crisis but CNT based membranes have shown remarkable results in terms of water permeability, desalination capacity, solute selectivity, robustness, antifouling, energy savings and scalability. CNT-membranes could be used at all levels from the point of generation (POG) to the point of use (POU) treatments. These have potentiality to give potable water instantly and can serve as next generation universal water filter [18].

6. Conclusion:

Over the conventional process engineering, the adaptation of highly advanced nanotechnology offers new opportunities for development of wastewater technology processes. Advancement in coming nanomaterials like Nano-membranes, nano-adsorbants, and nanoparticles suggests that many of the prevailing problems related to wastewater can be resolved or greatly diminished by using nanotechnology-based treatment which has a great and significant impact on water quality in natural environment. Hence, nanotechnology-based wastewater treatment is not only overcoming major challenges faced by existing treatment technologies, but also provides new treatment capabilities that could allow the economic utilization of unconventional water sources to expand the water supply.

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