

Applications of Nano-biotechnology in wastewater treatment

Water is one of the most important resources for sustaining human life. Exclusivity of water is considered central to evolution of life on earth. Reliable and sustainable supply of water is one of the most basic humanitarian goals and yet remains a challenge to meet globally. Major civilizations developed around riverine systems due to availability of ample supply of water and fertile land. Providing clean and affordable water to meet human needs is a grand challenge of the 21st century. Worldwide, water supply struggles to keep up with the fast growing demand, which is aggravated by population growth, global climate change, and water quality deterioration. The need for technological innovation to enable integrated water management cannot be overstated. Nanotechnology holds great potential in advancing water and wastewater treatment to improve treatment efficiency as well as to augment water supply through safe use of unconventional water sources. Developments in nanotechnology have started providing reliable solutions for water and wastewater treatment. The range of candidate nanomaterials, properties and mechanisms that enable the applications, advantages and limitations as compared to existing processes, and barriers and research needs for commercialization will be discussed here. Application of biotechnology knowledge for development of antimicrobial nanomaterials, reduction of pollutants in water using nanomaterials and nanomaterials for removal of contaminants are some of the fields which have application of biotechnology.

Current and Potential application for water and waste water treatment –

Nanomaterials are typically defined as materials smaller than 100 nm in at least one dimension. At this scale, materials often possess novel size-dependent properties different from their large counterparts which might already be explored for the water treatment purposes. These properties may relate to the high specific surface area, such as fast dissolution, high reactivity, and strong sorption, or to their discontinuous properties, such as super paramagnetism,

localized surface plasmon resonance, and quantum confinement effect. Most applications are still in the stage of laboratory research.

1) Adsorption

Adsorption is commonly used to remove organic and inorganic contaminants in water and wastewater treatment. Nanosorbents provide significant improvement over conventional adsorbents with their extremely high specific surface area and associated sorption sites, short intraparticle diffusion distance, and tunable pore size and surface chemistry.

a) Carbon-based nano adsorbents

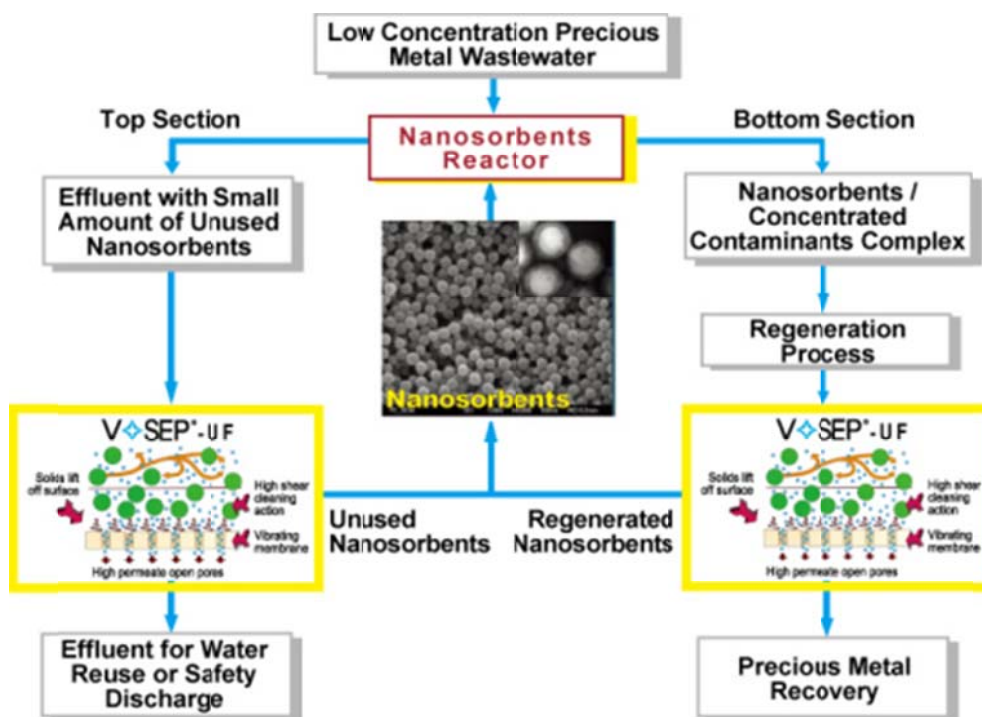
- Organic removal- CNT is better than activated carbon for removal of various organic wastes chemicals. Its high adsorption capacity is mainly due to the large specific surface area and the diverse contaminant-CNT interactions. In aqueous phase, CNT form aggregates due to hydrophobicity of their graphitic surfaces. These aggregates contain interstitial spaces and grooves for with high absorption energy for organic molecules. CNTs have more capacity for absorption of organic bulky molecules because of large pores in bundles and more accessible sorption sites. They absorb polar organic compounds due to diverse contaminant-CNT interactions like hydrophobic effect, pi-pi interactions (for polycyclic aromatic hydrocarbons, Polar aromatic compounds), hydrogen bonding (for compounds with -COOH , -NH_2 , -OH functional groups), covalent bonding and electrostatic interactions (for positively charged organic contaminants like antibiotics).
- Heavy metal removal- Oxidized CNTs have high adsorption capacity for metal ions with fast kinetics. The surface functional groups of CNTs absorb metal ions through electrostatic interactions and chemical bonding. Thus, surface oxidation can significantly enhance the absorption capacity of CNTs. They may not be a good alternative for activated carbon as wide-spectrum adsorbents, but since their surface chemistry can be tuned to target specific contaminants, they may have unique applications in polishing steps to remove recalcitrant compounds or in pre-concentration of trace organic contaminants for analytical purposes. Recently it was found that sand

granules coated with graphite oxide was efficient in removing Hg^{2+} and Rhodamine B with efficiency comparable to activated carbon.

- Regeneration and reuse- Adsorption of metal ions can be easily reversed by reducing the solution pH and adsorption capacity remains stable after regeneration. For example, CNT nanosorbents can be regenerated and reused for several hundred times for efficient removal of Zn^{2+} ions.

b) *Metal-based nano adsorbents*

Iron oxide, titanium oxide and alumina are effective adsorbents for metal ions and radionuclides. It includes fast adsorption of metal ions on the external surface followed by ratelimiting intraparticle diffusion along micro-pore walls.

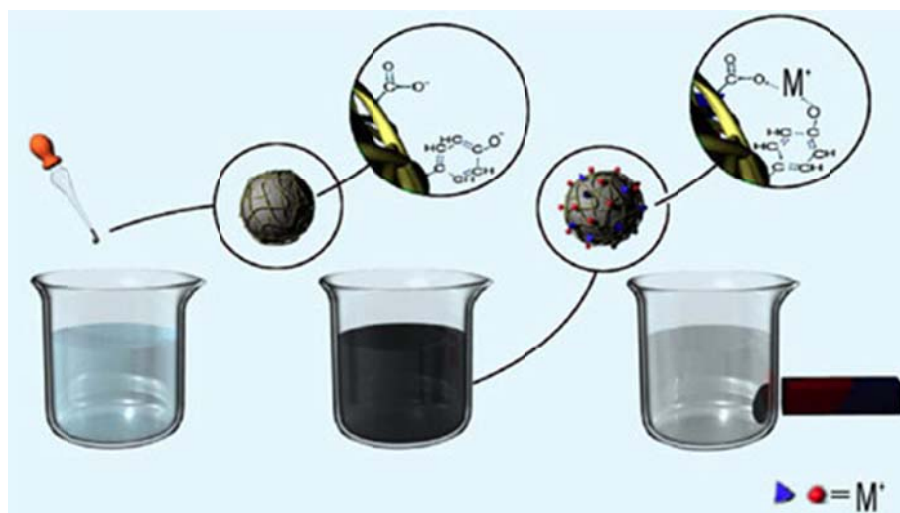


Dunwell group in Hongkong (<http://www.dunwellgroup.com>) adopts a type of polymeric nanoparticles, which is developed by The Hong Kong Polytechnic University, and has been successfully applied for wastewater treatment (shown above). The nanoparticles used in this process can effectively adsorb most of recalcitrant organic and inorganic contaminants present in wastewater. The saturated nanoparticles containing the adsorbed contaminants can be separated by using the vibrating membrane separation

system, and then easily regenerated for multiple uses without affecting their adsorption capacity for the targeted compounds.

Using magnetic nanoparticles for heavy metal removal –

Water pollution by toxic heavy metals occurs globally. Strict environmental regulations on the discharge of heavy metals and rising demands for clean water with extremely low levels of heavy metals make it greatly important to develop various efficient technologies for heavy metal removal. Numerous nanomaterials are in various stages of research and development, each possessing unique functionalities that are potentially applicable to the remediation of industrial wastewater, groundwater, surface water and drinking water. The main goal for most of this research is to develop low-cost and environmentally friendly materials for removal of heavy metals from water. A recent example is a novel low-cost magnetic sorbent material for the removal of heavy metal ions from water, developed by scientists in China, who coated iron oxide magnetic nanoparticles (Fe_3O_4 – magnetite) with humic acid (HA). The coating greatly enhanced material stability and heavy metal removal efficiency of the nanoparticles.



Overall scheme has been shown above in simplified manner. It is expected that the as-prepared Fe_3O_4 /Humic Acid has wide applicability in the removal of heavy metals from various waters (Jing-fu et al, 2008).

Antimicrobial Nanomaterials -

The antibacterial nanoparticles are classified into three general categories: naturally occurring antibacterial substances, metals and metal oxides, and novel engineered nanomaterials. These nanoparticles interact with microbial cells through a variety of mechanisms. The various types of antimicrobial nanomaterials are reviewed in this paper. The nanoparticles can either directly interact with the microbial cells, e.g. interrupting trans-membrane electron transfer, disrupting or penetrating the cell envelope, or oxidizing cell components, or produce secondary products (e.g. reactive oxygen species (ROS) or dissolved heavy metal ions) that cause damage.

Antimicrobial Nanomaterials and Disinfection Mechanisms

Various antimicrobial nanomaterials and their disinfecting mechanisms are reviewed from literature as following.

1) Chitosan and Peptides

Synthesized nanoparticles of naturally occurring chitosan and peptides have many potential applications in low cost water disinfection systems. The antibacterial mechanism of natural peptides is osmotic collapse through the formation of nanoscale channels in bacterial cell membranes. The antimicrobial properties of chitosan nanoparticles have been explained by various mechanisms. One theory proposes increase in membrane permeability and eventual rupture and leakage of intracellular components when the positively charged chitosan particles react with negatively charged cell membranes as the chief antimicrobial mechanism. Another mechanism proposes chitosan penetrates cell membrane walls and binds with DNA and thus inhibits RNA synthesis in cells. Potential applications of nanoscale chitosan and peptides include surface coatings of water storage tanks or as an antimicrobial agent in membranes, sponges.

2) Silver Nanoparticles - Nanoparticles of silver release large quantities of silver ions (Ag^+) when they interact with bacterial cells. These ions are very reactive and form reactive oxygen species (ROS) within the cells by reacting with thiol groups in the enzymes. ROS formation renders the respiratory

enzymes inactive leading to cell death. The structural integrity and permeability of the cell membrane is compromised by Ag⁺ ions which accumulate inside the membrane by forming pits causing large increase in membrane permeability. Ag⁺ ions also prevent DNA replication by damaging DNA and RNA. Silver ions also show photocatalytic activity in presence of UV radiation and this is useful in disinfection of microbes. Many current water purification and disinfection systems use membranes impregnated with nanoscale silver particles.

3) *TiO₂ Nanoparticles* - TiO₂ shows excellent photocatalytic activity in presence of UV radiation. The antibacterial activity of TiO₂ is mainly due to ROS production, especially hydroxyl free radicals and peroxide formed under UV irradiation by means of oxidative and reductive sequence of chemical reactions taking place within a cell. One of the important features of disinfection using TiO₂ nanoparticles is their ability to show photocatalytic activity even in presence of visible sunlight. This can be enhanced by doping TiO₂ with various metals. TiO₂ is widely used in many disinfection applications now-a-days. TiO₂ is suitable for applications in water treatment because it is stable in water, non-toxic by ingestion and low-cost. TiO₂ can be applied as a thin film coated on a reactor surface or a membrane filter or as a suspension in a slurry UV reactor.

4) *ZnO Nanoparticles* - Similar to TiO₂, nano-sized ZnO also shows high UV absorption efficiency and photocatalytic activity. One of the main mechanisms of photocatalytic degradation by ZnO is attributed to generation of hydrogen peroxide within the cells.

Conclusion - Clean water is essential and critical for all human activities ranging from simple household chores to the very complex industrial and agricultural processes. Current water distribution and supply concepts are inefficient owing the various drawbacks of these systems which include large demand on resources, low efficiency in water purification and treatment, high cost of operating the plant, chances of contamination during transport to remote locations etc. Current water purification and wastewater treatment methods can control the organic and inorganic wastes from water. But, these

methods are energy intensive and uneconomical because of non-reusable membranes and filters, inability to completely purify water, inability to make reuse of the retentate, etc. Various key issues and challenges still remain in successful incorporation, scaling up and commercialization of nanotechnology applications in inhibiting the bacterial pathogens, removal of heavy metals, xenobiotics leading to water purification and wastewater treatment. The ability to synthesize cost effective nanomaterials and their availability at industrial scale will determine the progress rate at which nanotechnology applications are accepted on industrial level. This chapter gives an overall glimpse of the applications of nanobiotechnology in controlling the water quality in waste water.

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