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Application of nanotechnology in waste management-An overview

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Abstract
The current global municipal solid waste generation levels are approx. 13 billion and expected to further rise from 9.3 – 10 billion by 2050. The adverse effect may not only affect the human health but it also includes flora, fauna, soil quality, ground water, air of that region. Therefore there is an urgent need to reduce and eliminate solid waste management systematically. The application of nanotechnology in waste management is a effective way to minimize the wastes. Nanomaterials show increased reactivity for adsorption, oxidation, reduction, catalyses, several contaminants such as heavy metals, organic and inorganic substances. Zero-valent iron (nZVI) is most extensively used nanomaterial in reductive degradation of organic contaminants (Chlorinated Hydro Carbons). Titanium Dioxide (TiO_2) is another metal based nanomaterial used as adsorbant for heavy metals. The Carbon Nano Tubes (CNT) arecarbon based nanomaterial act as adsorbant for polar, non-polar organic compound soils. Thus it is anticipated that the application of nanotechnology in waste management going to reduce cost and energy demand and increase process efficiency in environment protection industry.

Keywords: adsorption, oxidation, zero-valent iron (NZVI), chlorinated hydrocarbon, carbon nanotubes (CNT) and titanium dioxide (TIO_2)

Introduction

Nanotechnology is currently applied in several technology and industry sectors, such as medicine, energy, food safety and electronics and thus in many everyday life applications. In addition, nanotechnology is also one of the most important emerging trends also in environmental protection industry and particularly in waste management. This technology employs materials with at least one dimension less than 100 nm, so called nanomaterials. Owing to their size, nanomaterials demonstrate increased reactivity for adsorption, oxidation/reduction and catalysis of several contaminants groups, such as heavy metals (e.g. chromium), organics (e.g. chloroethenes) and inorganic (e.g. nitrate).

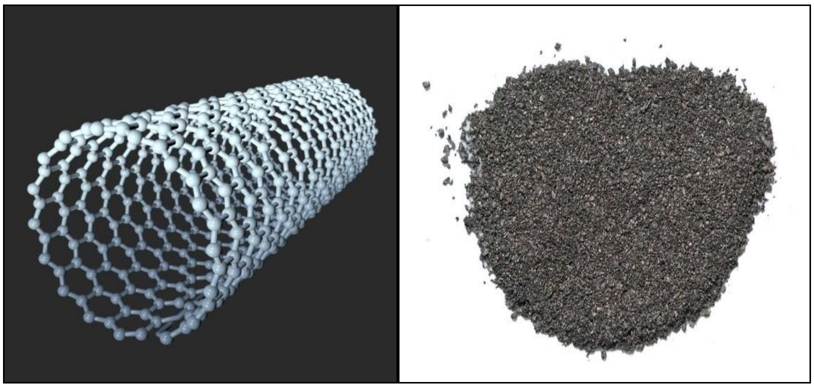
The application of nanotechnology has shown great promise as a more effective alternative compared with many conventional waste treatment technologies. The application of nanomaterials is able to increase treatment effectiveness for persistent contaminants better than conventional chemicals, owing to their increased reactivity and selectivity.

In addition, nanomaterials are able to undergo chemical reactions that were impossible using conventional materials. Regarding the application effectiveness, nanomaterials may very well lead to the simplification of treatment, reducing the demanded traditional treatment steps and consequently reducing the energy, the cost and the required treatment time.

However, there still remain some critical questions awaiting convincing answers mainly concerning the nanomaterials potential toxicity and their fate and transport in the environment, not only for those used in environmental protection industry but mainly for those already widely used in everyday life applications. (Malanowski *et al*., 2007) [1]. The efficiency of nanotechnology in waste management mainly depends on the selection of suitable nanomaterials for the targeted contaminants and the prevailing conditions.

Nanomaterials manufactured at industrial scale

Even though various nanomaterials have been produced in laboratory-scale conditions so far, only few of them have been finally manufactured at industrial scale. Metal (mostly iron) and carbon-based nanomaterials are presently among the most commonly used, while zero-Valent iron (nZVI), Titanium dioxide nanoparticles are the most extensively used nanomaterial in the environmental protection industry. Among carbon-based nanomaterials, the carbon nanotubes (CNTs) are the most common. CNTs are allotropes of carbon with a cylindrical nanostructure and, depending on their manufacturing process, CNTs can be categorized as single- or multiwall CNTs. (Vollath 2008) [2]



Carbon Nano Tube (CNT) Zero-Valent iron (nZVI)

Fig 1

Nano treatment technique

Conventionally adsorption technique is the most technical, economical and a viable option. Research in waste disposal treatment with adsorption technique has resulted in formation of specific materials for ejection of metals from solution, these material include natural products like activated Carbon, Aluminosilicates, Peat Kaolin, Zeolite, Clay, and Polysaccharides. At present carbon based nanomaterials specially in the structure of carbon nanotubes are being used as unique adsorbents with high efficiency because its specific surface area is high. (Sharma 2012) [3].

Multiwall carbon nanotubes (MWCNT) are having metal-ion sorption power of many times larger than the normally used powder and activated granular carbon. Nanomaterials can be used to build structures` that have controlled shapes, density and dimensions for specific filtration applications. Cylindrical membranes with pores tiny enough to filter out the smallest organisms have been developed. Carbon nanotubes are a class of nanoscale materials used in various forms of water filtration. So the power requirement for Nano-Filter is much lower than reverse osmosis process, for Nano- Filter operates at lesser pressure, generally in the regime of 50-150 psi. Nano Filter film mostly reject ions of divalency at a very higher rate than ions ofmonovalency. (Nystrtm *et al.*,1995) [4]

Nanotechnology in the waste management

ZeroValent Iron (nZVI)

ZeroValent Iron (nZVI) is a very effective material in the reductive degradation of organic contaminants (e.g. chlorinated hydrocarbons). In addition, owing to its very high surface area, nZVI can act as an adsorbent for heavy metals (e.g. hexavalent chromium), which are transformed to non-toxic forms via redox reactions occurred on nZVI surface (Dermatas *et al*., in press). High efficiency has also been proved for nZVI in removing inorganic contaminants (e.g. nitrates) from liquid waste streams. The extensive use of nZVI is also attributed to its capability for surface modifications in order to increase its selectivity towards specific contaminants and its stabilisation. In addition, the incorporation of a second, usually noble, metal like palladium or platinum (bimetallic nZVI), increases the effective surface area and usually catalyses the redox reactions and, thus, significantly enhances the reaction rate with the targeted contaminants. To this end, various polymers, and other coatings, have been used to stabilise ZVI particles, with varying degrees of success. Nano-sized titanium dioxide is another common metalbased nanomaterial. (Li *et al*., 2006) [7]. These nanoparticles are mainly used as photocatalysts owing to their high photosensitivity, but also as adsorbents for heavy metals. When this nanomaterial is exposed to ultraviolet (UV) light (sunlight) it produces hydroxyl radicals, which are highly reactive and can oxidise contaminants. Hydroxyl radicals are used for water treatment in methods generally termed advanced oxidation processes. Titanium dioxide has a wide band gap energy that requires the use of UV light, as opposed to visible light only, for optimal photocatalytic activation. As catalysts, these nanoparticles, remain unchanged during the degradation process. They are capable of undergoing different reduction processes since they are chemically stable and insoluble in water. Owing to the production of hydroxyl radicals they exhibit strong antimicrobial activity. The low toxicity and the low production cost are two more advantages of titanium dioxide nanoparticles. (Yaroshchuk and Staude 1992) [5]

Carbon nanotubes (CNTs)

Among carbon-based nanomaterials, the carbon nanotubes (CNTs) are the most common. CNTs are allotropes of carbon with a cylindrical nanostructure and, depending on their manufacturing process, CNTs can be categorized as single- or multiwall CNTs. CNTs exhibit high specific surface area and are characterized by highly assessable adsorption sites.

Their adjustable surface chemistry (mainly owing to their tubular structure) and the capability for surface functionalisation enhance their sorption capacity. (Sinnott and Andreys 2001) [9] As a result, CNTs act mainly as adsorbents for heavy metals, polar and non-polar organic compounds and oils. The regeneration and the reuse of CNTs is their main advantage compared with other nanomaterials and obviously towards other conventional carbonaceous products like activated carbon.

Metal Based Materials

Apart from the aforementioned nanomaterials, other metalbased materials, such as zinc, silver, bimetallic or magnetic (e.g. magnetite) nanoparticles and polymeric nanoadsorbents have shown high efficiency for liquid waste management. However, the difficulty for scaling up their production is a crucial factor for not being widely applied as of yet. Nanotechnology can be employed either for in-situ or ex-situ waste management technologies. One of the most important representatives of in-situ technologies where nanotechnology can be used is the permeable reactive barrier, where a reactive zone is actually created vertically in the flow path of the targeted subsurface plume of contaminant. (Dermatas and Panagiotakis 2018).

Nanomaterials in ex-situ waste management

Nanomaterials are also used in ex-situ waste management technologies. These technologies are commonly based on processes such as adsorption, membrane filtration and separation and photocatalysis. Owing to their size, nanoparticles exhibit high surface area enhancing, thus, the adsorption of pollutants on their surface. As with regards to membrane filtration and separation, it is a process that has gained significant interest in recent years. Membranes act as barriers depending on their pore size and the contaminant molecular size. Nanomaterials can be applied for creating nanocomposite membranes either by their embedment in the membrane matrix or by the deposition on the surface.

The addition of nanomaterials, such CNTs, in polymeric membranes results in improving the mechanical properties of the membrane and increases the water permeability and the resistance to fouling. Finally, photocatalysis is an advanced oxidation process causing oxidative effects to contaminants and microorganisms. A variety of organic contaminants can be degraded by heterogenousphotocatalysis occurred by photocatalysts, such as titanum dioxide nanoparticles. However, the combination of separation and catalytic processes is a new trend that is still gaining momentum. This combination will lead to the creation of membrane photocatalytic reactors, which will be capable of treating liquid waste streams by simultaneous retention of the catalytic nanoparticles. (Nurmi *et al*., 2005)

Limitations and challenges of the Nanoparticles

On the other hand, the main disadvantages of nanoparticles are their aggregation, the problematic storage owing to their high reactivity and the decrease of reactivity with storage and application elapsed time. Moreover, further work is required to elucidate the complexities associated with such applications at field scale. In particular, they may also react with various naturally occurring water constituents significantly impairing their potential reactivity with the target contaminants (passivation). Another problem that has hampered the widespread implementation of such nanomaterials so far is their poor mobility in porous media, such as soil.

Although it has been demonstrated that the nanoparticle materials, usually, are not able to threaten the ecosystem, there are concerns that their nanosize and subsequently their unique properties, like shape, reactivity, conductivity and mobility, make them potentially harmful. Nanoparticles might be ingested,inhaled or uptaken through the skin. In order to determine the potential risks of nanoparticles, it is necessary to understand the behaviour and fate of nanoparticles after their introduction to the environment. Several ecotoxicological studies have shown the toxic effects of nanoparticles on mammalian cell types and to some aquatic organisms like daphnia or fish. (Darwish *et al*.,) However, there is still poor understanding of how nanoparticles affect humans and other animals. The lack of data for determining the immediate effects of nanoparticles on humans and the environment for use in setting toxicity thresholds is the basic reason for why laws and regulations concerning nanomaterials are being developed internationally. Despite the awareness of the potential risks of nanomaterials, their production has been industrialised while, only some general regulations about their use exist so far. In the European Union, the production and use on nanomaterials is under the regulation of REACH (Registration, Evaluation, Authorization and Restriction of Chemicals), while the United States EPA (Environmental Protection Agency) uses administrative orders or rules that fall within the regulation of the Toxic Substances Control Act, in order to control the nanomaterials manufacturing.

Conclusion

The application of nanotechnology in waste management is gaining momentum globally owing to the unique properties of nanomaterials and their high compatibility with the existing conventional treatment technologies. By determining the real impacts of nanomaterials on the ecosystems and balancing the technological advantages and the risks, it will be easier to create a rational legal framework concerning their environmental application. It is generally anticipated that application of nanomaterials is going to reduce the waste management cost and energy demands and increase the process efficiency.

However, their high production cost limits their industrial production for the time being. More importantly, there are still significant knowledge gaps concerning their fate, and transport and potential toxicity on human health and the environment that must be addressed and clarified before nanotechnology is widely applied in the waste management industry.

Therefore it is necessary for the scientific community to gain more specific knowledge of the potential toxicological effects of nanomaterials on human health and the environment before implementing their widespread use in industry in general and for waste the treatment.

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