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REVIEW ARTICLE

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Toxicological and Environmental Implications of Nanoparticles

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ABSTRACT

Nanotechnology provides technological solutions to many environmental problems and cleaner production and eventually reducing consumption of resources along improved chemical reactions. The darker side of nanoparticles is their health and environmental impacts, as nanoparticles have toxic effects. Nanoparticles are often coated with a different material than the core, but these coatings are expected to interact with the environment, causing health issues. Carbon nanotubes cause a specific type of cancer called mesothelioma and damage DNA, resulting in serious health risks.

Keywords: *Nanomaterials, Environmental contamination, Nanotoxicology, Environmental remediation.*

INTRODUCTION

Nanotechnology provides unprecedented technological solutions to many environmental problems and cleaner production and eventually reducing consumption of resources along improved chemical reactions. Nanotechnology delivers cleaner production (e.g. through green chemistry, synthesis and processing of nanoscale materials that reduces consumption of raw materials and natural resources such as water and energy, and improved chemical reactions and catalysis). Environmental nanotechnologies have the possibility to contribute to economic growth and innovation while at the same time allowing sustainable development and protecting the environment (Abegunde et al., 2025). As particles decrease in size, they acquire interesting and novel physical, chemical and electronic properties. Advantages include unique catalytic properties that can accelerate oxidation or reduction reactions with various pollutants for particle size less than 10 nm.

Nanoparticles can be used in soil remediation through the interaction of mineral strata, soil and resident micro-organisms, in order to engineer more efficient systems, for example, nickel that has leached into groundwater from industrial sites or natural pyrites can be absorbed by natural chalk or calcite. Similarly, different iron oxide minerals can be used to remove heavy metal and arsenic contaminants from groundwater.

Nano-sized silver particles acting as bactericides. The cells of bacteria are damaged in the presence of nano-Ag, finally resulting in death of the organisms. And the interaction with the cells is size-dependent which seems to depend also on the shape of the particles. So, we can say Nickel, SnO₂, ferric oxide-based nanoparticles can be used for treating and remediating environmental contaminants. Nanoparticles made from zinc oxide can be used to extract unwanted agricultural by-products from soil and water using nanofiltration membranes which consist of a multilayer structure with coating in the top layer, which is ultrathin. Nanofiltration is one of the most recently developed processes, aiming at a compromise between a high product quality and low energy consumption (Ban Der Bruggen, 2007).

Trends in nanotechnology can be utilized to clean up toxic waste sites. Researchers have developed sponge-like nanoporous materials that will mop up pollutants in air and water, and break down noxious wastes, therefore reducing greenhouse gases. ZnO film-based nanosensors should be useful in applications such as monitoring the quality of drinking water, or assessing contamination in underground water (Kamat et al., 2003). These are used as conductometric gas sensors and also to destroy highly toxic and chemical contaminants by cleaning up waste streams of contaminants. In Nanosensors, Solar photocatalysis method is used to detect and track pathogens, nutrients and allergens and in agriculture the nanoparticle can improve the quality of production by detecting pesticides, fertilizers, and biological events. Similarly, some nanoparticles use sunlight to break down organic pollutants thus monitor biochemical threats harms. The photocatalysis method is an active method which harnesses Ultra Violet energy from the sun to degrade many different pollutants such as nitrous oxides (NO_x) and volatile organic compounds. Titanium dioxide nanoparticles can be immobilized on substrates (Byrne et al., 2007), through a number of processes or be applied as thin films. Titanium dioxide nanoparticles have been doped with boron to harness visible light and therefore can be effective remediators of indoor air. Combining solar light with photocatalysts can destroy a variety of dangerous pollutants in air.

Titanium dioxide nanoparticles have shown significant efficacy in this respect and have already been incorporated in paints and cement for construction products. Combining solar light with photocatalysts can destroy a variety of dangerous pollutants in air (A. Orlov, 2007). The TiO₂ based photocatalysis is also being used for controlling indoor pollution. Moreover, they are now being adapted for drinking and groundwater remediation (Fiordaliso et al., 2022).

Clear and adherent films of titania are being used in optical coatings, therefore, it is possible to use photocatalytically active films as self-cleaning windows and automotive windshields (Bahnmann, 2007). Also, it is seen that doping TiO₂ with metal ions with radii larger than Ti⁴⁺ should primarily result in modifications of its surface properties. Along with these benefits which have been observed by using nanoparticles, the darker side of the nanoparticles is on health and environmental as the nanoparticles has toxic effect which has potential negative environmental impacts causing environmental risks. Within the past number of years several studies have indicated that exposure to specific nanoparticles, can lead to adverse effects in humans (Lam et al., 2007; Sing et al., 2012). Chemicals required for nanoparticles are often highly toxic, as are many nanomaterials. Nano-Ag appears to be significantly more toxic than Ag-ions and the presence of light is a significant factor increasing the toxicity.

Nanoparticles are often coated with a different material than the core. About 90% of TiO₂ nanoparticles which is used for photo-catalysis work are coated to radically alter the toxicological properties of nanoparticles but these coatings are expected to interact with the environment causing health issues (Qamar et al., 2024, Fiordaliso et al., 2022).

Another widely used nanoparticle is carbon nanotube which was first observed in 1991 by Sumiolijima. Carbon nanotubes are cylindrical single sheets of carbon atoms or molecules, typically a few nanometers in diameter. They are very strong, conduct heat efficiently and have unique electrical properties that make them potentially useful in many fields such as optics, electronics and architecture. They have been shown to be useful in hydrogen fuel cells because of their huge surface area and help to cause chemical reactions. Also, 'nanomedicines' allow more targeted therapy, where these tiny particles can be specifically sent to organs that are otherwise difficult to reach. Hence demands for carbon nanotubes are growing day by day (Poland et al., 2007). They can be made either by laser ablation using graphite as a starting material or made from CH₄ or carbon containing gases through chemical vapor deposition. Resulting carbon nanotubes may consist of a single layer of Carbon, single-walled carbon nanotubes, double layers, or multiple layers of Carbon. A specificity of carbon nanotubes is that they are light and have high mechanical strength. Single-walled carbon nanotubes are believed to have superior mechanical strength and thermal and electric conductivity. Also, they have conductive properties which depend on the symmetry of the C-C bonds.

Now the serious concerns about carbon nanotubes are health and environmental risks. In early studies researchers did not observe any cutaneous irritation in humans (Huczko et al., 2001) but now it is seen that some carbon nanotubes can cause asbestos like health harm if inhaled. Indicators of the harmful effects usually caused by asbestos were monitored when they get inhaled, such as inflammation and the production of scar-like structures or lesions (Zhang et al., 2021). Hence, carbon nanotubes, which are proposed for super-capacitors and lightweight parts for planes, cause a specific type of cancer called mesothelioma (Poland et al., 2007) and damage DNA, resulting in serious health risks. Certain carbon nanotubes cause inflammation, granuloma development, fibrosis and artery 'plaque' responsible for heart attacks. When cultured human lung cells treated with the nanotubes and nanofibers, change in the DNA observed which indicates a direct link between the dose of carbon nanotubes and the amount of damage.

The amount of surface area of a substance affects the interaction of chemicals in that substance with the environment. Smaller particles, nano particles, would result in a great deal of surface area. Thus, there will be a dramatic increase in the interaction between that substance and the environment if its particle size changes from macro to micro to nano. The results revealed damage to DNA from zinc oxide nanoparticles at higher concentrations 0.8 micrograms/ml after six hours of exposure (Zhang et al., 2021). The data also demonstrated that the nanoparticles caused oxidative stress in the cells, even at low concentrations. Its findings also indicate that nanoparticles are likely to cause extensive lung disease if entered the lungs and move into fine blood vessels to accumulate in several organs.

There is then the potential for the nanoparticles to translocate, or move through the cells lining the lungs, and cross into the fine blood vessels of the lungs. From there they could circulate throughout the body causing danger to human being.

Ecotoxicological studies show that nanoparticles are also toxic to aquatic organisms, both unicellular (e.g. bacteria or protozoa) and animals (e. g. fish). Carbon nanotube induced a dose-dependent growth inhibition in a protozoan and was found to be a respiratory toxicant

in rainbow trout (Nowack et al., 2007). However, the acute toxicity was only observed at the highest concentration only.

FUTURE ASPECTS OF NANOTECHNOLOGY

Nanotechnology is an area where research and development are growing fast and attract substantial funding, both from public and private sectors. According to Lux Research, a New York- based independent intelligence and advisory firms, investments in the nanotechnology industry grew from \$13 billion in 2004 to \$50 billion in 2006 (Lam et al., 2007). By 2010 the total world market for applications based on environmental nanotachnologies has been estimated to be \$6.1 billion (Rickerby, 2007) and will reach \$2.6 trillion by 2014 (Erik et al., 2007). This can be divided into four sectors: remediation, protection, maintenance, and enhancement, of which remediation is the fastest growing, maintenance and protection applications constitute the bulk of the remainder, while environmental enhancement represents the smallest sector. Numerous applications of remedial nanotechnologies are already close to market and, once performance and safety have been verified in field trials, these have potential for very rapid growth (Rickerby, 2007).

CONCLUSION

The knowledge about the toxics of nanoparticles is relatively low and to prevent the toxic effect of nanoparticles we need better governance of technological innovations, key industrial and research policies. Seeing around the potential benefits of developments in nanotechnology, we overlook some serious and chronic potential negative impacts. Thus, the concept of “Safety by design” is an illusion.

Before a product is applied or comes to market, it must be tested for safely. That is the rule for all products – drugs, chemicals, materials, etc. It is no different for nano-products and processes. So, if a product is properly and thoroughly tested, the potential risks will have been identified. When applying established toxicity tests to nanoparticles the results should always be interpreted with great care especially to avoid the reporting of strict preventive procedures is the only way to prevent any risk of occupational disease.

We can also introduce regulations to protect human health from the risks of inhaling nanoparticles and exploring the extent to which current regulations cover risks of nanomaterials and also case approach for the risk assessment of nanomaterials.

Technology must operate in the service of society, which means that it needs to be operated and headed by societal structures. Public debate on its progress and acceptable development is needed, and on obligation for damage done. Key industrial and research policies should include elaborated sustainability objectives which include reduced environmental impact and further, using sustainability assessment of technological developments which must have impact on environment. So, we can say, with better governance of the technology we can reduce the side effect of this precious technology which has the capability to cure many human health and environmental ailments.

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