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Role of nanotechnology in environmental pollution remediation

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ABSTRACT: With the increased industrialization and change in human life style, there has been remarkable increase in the pollution level in air, soil and water. Poisonous gases released in the environment from the vehicles and hazardous chemicals disposed from industries are serious threats to mankind. Parallel to this attempt are being made to control the pollution so that the pollutants may remain upto certain permissible level. In such scenario, advancements in technology play a crucial role to control the pollutants beyond the permissible limit. In the last few decades Nanotechnology is an emerging branch which has diversified applications in human life. Nanoparticles are the particulate materials of less than 100nm and high surface area, thus showing higher reactivity, better electrical conductivity and hardness. These properties render them useful for a wide variety of applications, including control of environmental pollution. But in the recent years, the new problem of 'Nanopollution' has emerged which poses risks for the safety of living organisms as they may remain suspended in the air for a long time, may accumulate in the environment or maybe even absorbed in the body. This review discusses the role of nanotechnology in controlling the pollution, purifying the air, water and soil as well as safe disposal of hazardous waste materials.

Key words: Nanotechnology, nanoparticles, nano magnets, pollution control

The adverse anthropological actions have led to a manifold increase in environmental pollution in all domains of air, water or soil, eventually affecting both animal and human health (Manisalidis *et al.,* 2020). Due to massive industrialization and man-made catastrophes, many air and water pollutants have filled the environment namely, Carbon monoxide(CO), chlorofluorocarbons(CFCs), heavy metals, hydrocarbons, industrial waste water , fertilizer, etc (Yunus, Kurniawan, *et al.,* 2012).Nanotechnology is one of the emerging methods to combat environmental pollution because nanomaterials have unique surface chemistry, higher surface to volume ratio and tunable physical properties, thus conferring to them enhanced reactivity and effectiveness (Guerra *et al.,* 2017, 2018). Nanomaterials have some additional properties such as greater catalytic activity, excellent electrical conductivity, hardness, electrochemical signals increment and retention of nanomaterial activity for a long time(Mohamed, 2017). These properties render them useful in manufacturing of excellent sensors, adsorbents, photo/electro-catalysts, nanofilters, nano-magnets as well as disinfectors (Yang *et al.,* 2019). Nanomaterials have an advantage over conventional materials which require more energy as well as raw material to get produced or maybe harmful to the environment (Masciangioli and Zhang, 2003). New Nanocatalysts have been introduced which can even work at lower temperatures than conventional catalysts and hence are energy efficient (Thayer *et al*., 2006).

Photocatalytic oxidation, nanostructured catalyst materials like nanospheres, nanoplates/sheets, nanotubes/rods, and nanoaero gels are gradually coming in use to combat air pollutants and purify air (Saleem *et al*., 2022). Similarly, for wastewater management, some nanotechnology-based pathways employed are Nanofiltration, nano-adsorption and biosorption, Photocatalysis and disinfection (Jain *et al*., 2021). Titanium based nanomaterials have also been reported for removal of arsenic from water (Ashraf *et al*., 2019). Unequivocally, a huge area of research has been carried out to harness the best of nanotechnology and to highlight such investigations; this review canvasses the varied applications of nanotechnology in purification of water, air and soil along with its role in disposal of toxic waste materials.

Nanoparticles for Purification of Air

With the increased advancement in the field of nanotechnology, the potential of nanoparticles (e.g., carbon-based nanoparticles, antibacterial nanoparticles, and metal oxide nanoparticles) for procuring clean drinking water and fresh air is unequivocally huge in air purification (treatment of greenhouse gases and volatile organic compounds through adsorption, catalytic degradation, and air filtration processes), as well as in purification of water (Ibrahim *et al.*, 2016). Air pollution due to the presence of toxic gases and particulate matter is an important factor violating health of animals. Nanofibrous membrane is a reliable filter to capture particulate matter. Electrospinning is known to be the best way of fabricating nanofibrous membrane (Ojstršek *et al.*, 2020). Such electrospun membranes exhibit impressive PM 2.5 filtration performance.

Most common is the single needle electrospun nanofibrous membranes with bead-on- string structure(Kadam *et al.,* 2019; Lyu *et al.,* 2021). This filter also possesses antibacterial property as it is now prepared with antibacterial agents like $AgTiO_2$ as in case of PAN/PU membrane (Polyacrylonitrile/polyurethane). It works excellent against *E. coli* and *Staphylococcus* (Lyu *et al.*, 2021). The indoor air quality for housed animals is a matter of concern for all the farmers as the atmosphere is one major communication between polluted outdoors and clean indoors. Use of silver nanoparticle and copper nanoparticle filters can remove bioaerosols like viruses, bacteria *Bacillus subtilis, etc.* (Joe *et al.,* 2016; Yoon *et al.*, 2008). Nanotechnology has also been used in the detection of the antiviral antibodies (Jain *et al*., 2018) and the role of Nano biosensors in the detection of animal diseases has been reviewed in detail (Tewari *et al*., 2021a). Nanotechnology can help prevent air pollution by elimination of waste generation in process like industrial manufacture. Metal organic frameworks remove particulate matter (Mohamed, 2017).

Similarly, there are following major ways in which nanotechnology is proving to be of utmost benefit in treating the polluted air:

Adsorption by nano-absorptive materials

Carbon nanostructures, owing to their properties like average pore diameter, pore volume, and surface area, are one of the most effective Nanoadsorbents for industrial application, with high selectivity, affinity, and capacity (Sabzehmeidani *et al.*, 2021).

Various nanoadrobtive materials used for the purpose are Carbon nanotubes (CNTs), graphene, fullerene, etc. (Mohamed, 2017).Nanoadsorbents can also detect and adsorb pollutants such as metal oxides, volatile organic compounds (VOCs), and even certain microorganisms (Saleem *et al.*, 2022).

Degradation by nanocatalysis

The nanoparticle size and molecular structure/distribution can be altered using nanotechnology for creating new nano-catalysts with greater surface area. Nano catalysts are quite effective in improving air quality and eliminating air pollution to a lower degree by degradation of volatile organic compounds like benzene, toluene, formaldehyde, etc.(Tai *et al*., 2020).Photocatalysts such as titanium dioxide (TiO_2), zinc oxide (ZnO), iron (III) oxide (Fe_2O_3) and tungsten oxide (WO_3) can be used for ultraviolet light absorption, as automatic cleaners and for removal of water contamination (Yunus, Harwin, *et al.*, 2012). Rapid and selective chemical transformations are possible with the help of nanocatalysis. It additionally provides greater product yield along with catalyst recovery, in contrast to the conventional catalysts (Mohamed, 2017).

Filtration/separation by nanofilters

Nanostructured membranes are used as nanofilters that have pores small enough to separate various pollutants from exhaust of industrial chimneys and thus help in controlling air pollution (Khan and Lee, 2021).

Nanotechnology for Purification of Water

Sufficient and clean water supply is essential for health and ensures optimum productivity. Nanotechnology is emerging as the new hope to clean water. It makes the use of nanomembranes to soften water and eliminates all sorts of undesirable elements from water. Nanocoagulants could compensate for the flaws of the traditional coagulants like Aluminum Sulphate, can purify industrial wastewater and can even be used to removal of microplastics from wastewater (Ghorbani and Nikpor, 2021; Khoso *et al.*, 2023). Another viable product of nanotechnology still under development is the Magnetically active nanoparticles useful in the capture of chemical contaminants of drinking water (Martinez-Boubeta and Simeonidis, 2019). An important aspect of nanotechnology being used as water cleanser is the use of nano filters (PM 2.5 and PM 1.0) that resemble to silkworm cocoon by structure and so the filtration efficiency is maximum even with reduced filter pressure and therefore small water cluster essential for metabolism is resulted (Zheng-Biao and Ji-Huan, 2014). Affordable nano sensors have also been developed which when applied to all the clean water sources and service lines and then linked to our smart phones can also enable us to the know both local and global water quality and so act accordingly(Nagar and Pradeep, 2020).

Some of the applications where nanotechnology can be used in water purification are:

***Nanoadsorbents*:** Nano adsorbents are adept in removing both organic and inorganic pollutants. They are classified chiefly into metal-based, carbon-based and metal oxide-based nanoparticles. Their role as adsorbents for toxic chemicals from manufacturing and pharmaceutical industries is very efficacious (Kumari *et al.*, 2019).Nanoadsorbents possess a higher rate of adsorption for organic compounds compared with granular or powdered activated carbon, due to increased surface area. They are also efficient in removal of organic and inorganic pollutants like heavy metals and micropollutants. Some of the most popular nanoadsorbents in research area are (Gehrke *et al.*, 2015):

- o Carbon-based nanoadsorbents like carbon nanotubes (CNTs)
- o Metal-based nanoadsorbents
- o Polymeric nanoadsorbents
- o Zeolites, etc.

***Nano filtration*:** Nano filtration membranes (NF membranes) are widely used pressure driven membranes that can filter particles of up to 0.001-0.1 micrometer size. They can effectively remove turbidity, microorganisms and inorganic ions such as Ca and Na, and soften groundwater. They have also been useful in wastewater treatment and for pretreatment in seawater desalination (Bhattacharya *et al.*, 2013). Graphene oxide coated nanofiller membranes have been shown to be effective in dichlorination of water (Park *et al.*, 2016). Another nanomaterial, Nanocellulose, has shown very promising results as a membrane filter in water purification to remove contaminants from polluted water (Voisin *et al.*, 2017).

Nano catalysts: Photo catalysis using metal oxide semiconductor nanostructures have shown to be effective in degrading organic contaminants in water. They accelerate photoreactions without undergoing any physicochemical alterations themselves (Baruah *et al.*, 2008; Baruah and Dutta, 2009). Photo electrocatalytic dye degradation is also one of the techniques which is inviting substantial interest in degradation and safe disposal of chemical dye-containing waste water (Khan and Lee, 2021).

***Green Nanoparticles*:** Eco-friendly Remediation of pollutants is possible through the fabrication of ‘green nanomaterials’ from microorganisms and extracts of other organisms (Mandeep and Shukla, 2020). Iron nanoparticles are one of the most effective green nanoparticles for remediation, owing to their redox potential on reaction with water, magnetic susceptibility, and non-toxic nature (Bolade *et al.*, 2020).

***Nano- Magnets*:** Activated carbon modified nano-magnets have proved to be very efficacious in eliminating fluoride ions from wastewater. With an uptake of 454.54 mg/g, the nanocomposite was described to diminish 97.4% fluoride ion from synthetic wastewater by the process of sorption (Takmil *et al.*, 2020).

Nanoparticles for reducing soil pollution

Contamination of soil with toxic compounds and hazardous substances like insecticides, heavy metals, organic compounds, industrial effluents, fertilizers, and sewage is a severe threat to human health. Emerging nanotechnology has provided an ecofriendly, sustainable, efficient and cost-effective platform for remediation of above problem. The mobility and bioavailability of heavy metal present in soil can be reduced by the application of nanoparticles as they can absorb and transform them. They form complexes with heavy metal and make them unavailable thus hindering their migration towards plants (Zhou *et al.*, 2020). Zero-valent iron (ZVI) nanoparticle is a low-cost, non-toxic reducing agent used in nano remediation of contaminated soil. Its ability to oxidize to ferrous or ferric ion is utilized as the free electrons produced in this process can reduce other contaminants and make them non-toxic. They have been proved to be efficient in decontaminating inorganic compounds (perchlorate and nitrate) and heavy metal pollutants (arsenic, lead, nickel and mercury). When applied on polluted soil they react with contaminants and convert them into less toxic and less mobile products. They can be grouped as bimetallic iron-based nanoparticles, emulsified iron nanoparticles (EZVI) and polymer coated NZVI (Galdames *et al.*, 2020). Functionalized mesoporous silicon nanomaterial has been applied in reducing soil pollution as it has not only proved to be efficient in soil remediation but has also been helpful in determining in situ condition by measuring the bioavailability of organic and inorganic pollutants. Studies has shown its utility in remediation of copper, lead and cadmium in soil (Yang *et al.*, 2020). Metal nanomaterials such as gold, silver and carbon-based nanomaterials such as carbon nanotubes, graphite, and graphene are used in biosensor for the immobilization process. They are used in detection and accurate monitoring of heavy metal pollution (Maghsoudi *et al.*, 2021). EDTA based ligand-coated dense nanoparticle has shown fast, low cost and efficient in-situ remediation of cadmium and lead. They can adsorb most of bioavailable metal ion (Huang and Keller, 2020).

Nanotechnology for safe disposal of hazardous and toxic wastes

The current age of technology and industrialization has paved a way for enormous bulks and piles of hazardous waste, whose disposal poses a major threat. Hazardous and toxic materials are the byproducts of many industries like manufacturing, agriculture, hospitals, construction, etc. They may include a wide range of chemicals, radiations, heavy metals and even pathogens. Some of the common examples include paints, pesticides, clinical waste, persistent organic pollutants (POPs), strong acids and alkalis, arsenic, lead, cadmium, etc. The progress and research in the field of nanotechnology has put forward a few promising ways by which the safe disposal of some of these hazardous chemicals is possible. The nanomaterials, due to their high specific surface areas, can be very effectively used as catalysts, adsorbents, membranes, or additives to reduce or transform waste materials (Khan and Lee, 2021). Researchers all over the globe are focused on altering the waste materials in such a manner so as to change their properties. This approach will help to reduce waste and generate useful products concurrently. This perspective can be effectively used in the production of biogas, biohydrogen, adsorbents, clinker, biomolecules and many other products by the industrial sector (Mandeep *et al.*, 2020). Nanotechnology has proved to be very promising in enhancement of the production rate, ensuring the efficient transformation of waste materials into useful resources. For instance, the use of nanoparticles to enhance dark fermentation reactions, resulting in increased biohydrogen production has been successfully described (Kumar *et al.*, 2019). Additionally, supplementation of fermentative bacteria with nanoparticles has carved up newer boulevards for biohydrogen generation from wastewater (Elreedy *et al.,* 2019).

Other approaches

Regular surveillance of the pathogens is crucial to understand their epidemiology (Dash *et al*., 2012; Jain *et al*., 2019). Multiplexed based tests (Tewari *et al*., 2020) and confirmatory ELISAs (Tewari *et al*., 2021b) can play a pivotal role to detect the pathogens or the contaminant in the sample with more confidence. Such approaches (Tewari *et al*., 2020, 2021b) can be used to detect the pollutants from all types of samples.

CONCLUSION

The omnipresent problem of unchecked increase in pollution throughout the globe has grave detrimental effects on mankind. Thus, it becomes imperative to switch over to alternate pollution control programs apart from the conventional methods. Nanomaterials, owing to its unique physical and chemical properties, provide a promising future in treating air, soil and wastewater pollutants and contaminants. Nanocatalysts, nanoadsorbents, nanofilters, nano magnets, etc., are some of the forms which have emerged as successful alternatives to the existing conventional methods for environmental pollution remediation. Zero-valent iron (ZVI) nanoparticle is a low-cost, non-toxic reducing agent used in nano remediation of contaminated soil. Also, eco-friendly Remediation of pollutants is possible through 'green nanomaterials' from microorganisms and extracts of other organisms. However, amongst all these benefits, in recent years a new challenge of '*Nanopollution*' has emerged. It refers to presence of nanomaterials in the environment which can easily penetrate living cells due to their small size and cause adverse effects. They can easily get incorporated into air and water, and get accumulated in living cells through food chains. Hence, the harmful effects and hazards of nanomaterials on human and animal health as well as environment are thoroughly needed to be researched. A set of guidelines regulating the production and uses of nanomaterials can also prove to be helpful in optimizing and harnessing the benefits of nanotechnology.

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