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Use of bio-based nanoparticle for remediation of water and soil pollution

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Nanotechnology as a branch of Science has gained popularity since 1980s. Nanotechnology is finding its diverse applications in different arenas of today's world. Typically the size of nanomaterials ranges from 1 to 100 nm. These particles possess peculiar physicochemical properties than their bulk surfaces due to its smaller size and extensive surface area. Because of these reasons, they are being widely researched and applied in various fields like agriculture, engineering, medicine, food industry etc.

Classification

Based on the dimensions, nanoparticles are considered to be a zero dimentional nanomaterial which implies that their all three dimensions are in the nanoscale.

On the basis of constitution, nanoparticles are classified as i) organic ii) inorganic and iii) carbon based. Organic nanoparticles includes those which are synthesized from proteins, carbohydrates, lipids, and various other organic substances to achieve a defined size, specifically with a radius of < 100 nm (Pan *et al.,* 2016). Liposomes, micelle, ferritin, dendrimers are instances of organic nanoparticle. Inorganic nanoparticles are not synthesized using organic substances or carbon. It includes metal nanoparticles, ceramic nanoparticles and semiconductor nanoparticles. Carbon based nanoparticles are exclusively made of carbon atoms *viz,* carbon quantum dots, fullerenes and carbon black nanoparticles (Joudeh and Linke, 2022).

Metal based nanoparticles includes i) silver nanoparticles with antimicrobial properties ii) Zinc nanoparticles – widely used in electronics and catalysis iii) Copper nanoparticles used in electronics, catalysis, agriculture iv) Gold nanoparticles used in diagnosis, drug delivery, in sensors, catalysis v) Aluminium nanoparticles used in catalysis, biomedical field, energy storage operations vi) iron nanoparticles used in catalysis, sensors, imaging, drug delivery etc (Altammar, 2023).

Manufacturing of nanoparticles

Nanoparticles are synthesized using top down or bottom up approach. Top down approach refers to the conversion of bulk materials into nanoparticles while bottom up approach refers to the synthesis of nanoparticles from the atomic/molecular level. Figure 1 illustrates these two approaches. Physical methods of top down approach includes mechanical milling, electrospinning, laser ablation, sputtering, electron explosion, sonication, pulsed wire discharge, arc discharge, lithography; chemical methods of bottom up approach are chemical vapour deposition, sol-gel process, coprecipitation, molecular condensation, hydrothermal process; biological/green approach involves the utilisation of plants, microorganisms and biomimetics (Altammar, 2023)

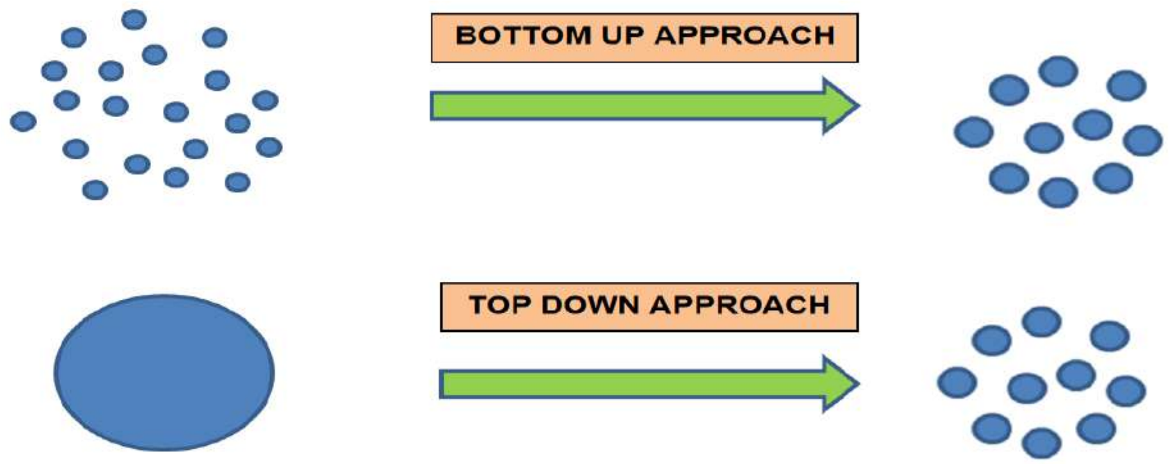

Fig 1: Top down and bottom up approach of nanoparticle synthesis

Biobased nanoparticles

Biobased nanoparticles are synthesized through novel technology which utilizes biological entities like bacteria, fungi, algae and plants to produce nanoparticles. In microbial based synthesis of nanoparticles microorganisms like bacteria, fungi, and algae are used for the nanoparticle synthesis. The key processes involved in the synthesis may be enzymatic reduction/ bioaccumulation followed by biomineralization/ cellular uptake and efflux system/ extracellular or intracellular synthesis/ as a part of cellular dynamics. Hence, the fundamental basis for the nanoparticle production in biobased synthesis is from the organic sources.

Regardless of the methodology employed, nanoparticles synthesized from the biological sources are considered to be biobased. For instance, chitosan which is a polysaccharide derived from chitin, found in the some crustaceans and insects is utilised for the synthesis of silver nanoparticles. Apart from chitosan based nanoparticles, cellulose based, protein based, lipid based nanoparticles etc are also examples for biobased nanoparticles.

Biobased NPs for water pollution remediation

Water, the elixir of life occupies seventy percent of planet earth, but only three percent of it is freshwater, among which two third is not readily available as it locked up in polar ice and glaciers. Increase in population growth, urbanization, soil pollution, industrialization, agricultural production activities etc are leading to water quality deterioration and pollution of water bodies. According to World Wildlife Fund, approximately 1.1 billion individuals do not have access to water, while 2.7 billion people every year faces water scarcity for a minimum of one month period. Hence, water pollution remediation need to be addressed with utmost care. Researches have indicated that biobased nanoparticles are having immense potential for remediation of polluted water.

Potential of biobased Nps for water remediation

Chen *et al* (2009) indicated the scope of using carboxymethylated bacterial cellulose biosynthesized from *Acetobacter xylinum* for Cu and Pb ions removal from waste waters. Biosynthesised gold and silver nanoparticles from stem extract of *Breynia rhamnoides* could reduce 4-nitrophenol to 4-aminophenol (Gangula *et al*., 2011). *Spirulina platensish* algae were utilized for the synthesis of cadmium sulphide nanoparticles which could act as a biosorbent and could degrade dye like malachite green (Mandal *et al.,* 2016). Dubey *et al* (2016) reported that chitosan alginate nanoparticles exhibited very high adsorption capability of upto 217.39 mg/g at 30◦C for mercury (II). Silver nanoparticles synthesized from *Guiera senegalensis* leaf extract showed its potential to degrade congored dye and 4-nitrophenol dye (toxic dyes used in the textiles and dyeing industries) (Bello *et al.,* 2017). Jin *et al* (2017) reported that bacterial cellulose pellicles from *Gluconacetobacter xylinus* ATCC23767 modified with polyethyleneimine following amination process have faster adsorption capacity for Cu and Pb ions. Biosynthesized iron nanoparticles from *Lagerstroemia speciosa* leaves exhibited the capacity to degrade methylene blue, methyl orange, allura red, brilliant blue, and green S dyes (Garole *et al.,* 2018). *Shewanella oneidensis* mediated biosynthesis of copper nanoparticles was reported. The same study indicated the bioreductive capacity of divalent copper by *Shewanella oneidensis (*Kimber *et al.,* 2018). *Deinococcus radiodurans* bacterial protein was used for the synthesis of gold – silver nanoparticles (Drp-Au-Ag nanoparticles) which was found to be efficient in degrading malachite green dye, a carcinogen still being in use in several countries (Weng *et al.,* 2020). Iron oxide nanoparticles synthesized from *Aspergillus tubingensis* fungi exhibited heavy metal removing capacity for lead, nickel, copper and zinc ions from waste water (Mahanty *et al.,* 2020). Arsenic content in water could be reduced to an extent of approximately 95 percent by the adoption of magnetite nanoparticles produced from *Fusarium oxysporum* fungi (Balakrishan *et al*., 2020). Chatterjee *et al.* (2020) found that *Aspergillus niger* BSC1 bacteria isolated from Sundarban biosphere in India could produce ironoxide nanoparticles having supermagnetic properties which was found to be highly efficient in remediation of chromium contaminated solutions with a removal capacity of more than ninety nine percent. Laslo *et al.* (2022) synthesized selenium nanoparticles using *Lactobacillus casei* bacteria which exhibited the capability for the removal of cadmium from aqueous solutions. Kara *et al* (2024) reported that succinic anhydride modified cellulose nanomaterial extracted from *Eichhornia crassipes* has the capacity to remove the nickel and lead from runoff wastewater (Kara *et al.,* 2024)

Biobased NPs for soil pollution remediation

Citrobacter freundii Y9 bacteria were utilized for the synthesis of selenium nanoparticles which exhibited capability to convert elemental form of mercury in the soil to mercuric selenide which is insoluble under aerobic and aneraobic conditions which indicated its potential to use it for remediation of mercury contaminated soils (Wang *et al.,* 2017). Zero valent iron nanoparticles synthesized using *Azadiracta indica* and *Mentha longifolia* were studied for their remediation potential in nickel and lead contaminated soils which suggested that the zero valent iron particles from *Mentha longifolia* were exhibiting better remediation capacity with respect to lead and nickel (Francy *et al*., 2020). Application of extracellular biosynthesized iron oxide nanoparticles from *Pantoea ananatis* RNT4 resulted in decrease in cadmium uptake by wheat crop to an extent of upto 72.5% (Manzoor *et al*., 2021). While, Shirkhani *et al.* (2021) found that chitosan nanoparticles (5% w/w) could enhance the phytoremediation potential of *Datura stramonium* in cadmium polluted soil.

Nanozerovalent iron composite synthesized from tea leaf extract and montmorillonite proved to be a cheaper green synthetic technology for remediation of chromium (VI) ions in soil and in water (Yang *et al.,* 2021). Ahamed *et al* (2023) prepared silicon nanoparticles using rice straw and the impact of these biogenic silicon nanoparticles revealed that weight of the crop, and antioxidant enzyme concentrations were higher in the treated plants which indicated that cadmium toxicity in rape seed plants could be managed using silicon nanoparticle application.

Iron nanoparticles synthesized from *Azadirachta indica* when treated with persulphate resulted in the degradation of approximately 99% of total petroleum hydrocarbons in the soil within a short time span of 5 days and 14 hours (Bolade *et al.,* 2021). The Pickering emulsions stabilized by acid treated rice straw derived cellulose nanocrystals were able to remove upto 59.1% of tetradecane, a common petroleum hydrocarbon (Yang *et al.,* 2025).

Bio-based NPs for remediation of heavy metals

Stenotrophomonas aidaminiphila soil bacteria were utilized for the production of selenium nanoparticles which could be used as a heavy metal toxicity detecting biosensor (Ahamed *et al.,* 2020). Gold nanoparticles synthesized using *Escherichia coli* K12 cells was found to be capable of complete reduction of 4-nitrophenol (Srivastava *et al.,* 2013). Chemically altered (treated with succinic anhydride) cellulose nanocrystals derived from cotton could indicated its potential to adsorb heavy metals like cadmium and lead (Yu *et al.,* 2013). Fe_2O_3 nanoparticle embedded bacterial cellulose nanocomposite biosynthesized from *G. xylinum* has adsorption capacities of 65, 33, and 25 mg/g of Pb^{2+}, Mn^{2+}, Cr^{3+} ions. Ha *et al.,* 2016 reported that *Enterococcus faecalis* recovered palladium nanoparticles could catalyse the reduction of hexavalent chromium, which is a carcinogen. Silver nanoparticles synthesized from *Gmelina arborea* fruits showed the calalytic degradation capacity of methylene blue dye within 10 minute timespan (Saha *et al.,* 2017). Bionanocomposite derived using *Penicillium* fungi – Fe_3O_4 was found to be effective in remediation of nuclear wastes like Sr, U and Th (Ding *et al.,* 2015).

Conclusion

Biobased nanoparticle synthesis possesses multiple advantages over chemical methods of synthesis as the former exhibits lesser environmental pileup, lower toxicity and better compatibility with the plant cells. Still, comprehensive understanding of the scientific principles and indepth analysis of the fate of nanoparticles is imperative so as to utilize the further potential of biobased nanoparticles for soil and water pollution remediation.

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