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Green Nanotechnology: Principal Role of Green Nanoparticles in Environmental Remediation and Wastewater Treatment

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Abstract

A recent development in nanotechnology is green nanotechnology. The major concerns of this technology are improving health status, ensuring sustainable energy, ensuring sustainable environmental and green economy, and reducing waste. This research is, therefore, concerned with the role of green nanotechnology and the potential role of green nanoparticles in environmental remediation and wastewater treatment. This technology is expected to effectively treat contaminated water, heavy metal-containing water, and polymer waste. Green nanotechnology is not limited to only wastewater treatment but also recycling technology. Hence, the role of green nanotechnology in recycling material is highlighted. The potential role of green nanoparticles in wastewater treatment and mitigating climatic change is seen. It is expected that green nanotechnology will enable nanoabsorbants, nano members, and nano filters which help to produce a clean water supply. The technology is also likely to yield green hydrogen which adds to energy security. This technique is expected to create a suitable environment free from pollution by realizing a clean water supply and secure, sustainable, and clean energy.

Keywords: Biopolymer, energy security, green nanotechnology, green hydrogen, wastewater, recycling

INTRODUCTION

Till today scientists, engineers, and industry professionals have been researching a better method of synthesizing smart materials, such as green nanoparticles. Devoting much effort, they can bring a new industrial revolution, “nanotechnology”. Nanotechnology is a technology that operates at a nano-size scale. The advancement in nanotechnology is further extended to “green nanotechnology”.

Green nanotechnology is the synthesis, fabrication, and utilization of nanomaterials in a sustainable way. Green nanotechnology is concerned with the green synthesis of nanoparticles which is secure, pollution-free, and environmentally friendly. It is the use of nanomaterials for recovering, recycling, and utilization of biomaterials. It is also the synthesis and fabrication of materials and devices by using green nanoparticles. The synthesis procedures incorporate natural resources, such as microorganisms, menotactic bacteria, viruses, proteins, liposomes, algae, fungi, liverworts, and green plants.

Nanomaterials synthesized by green synthesis methods are graphene nanoparticles, carbon nanotubes, chitosan nanoparticles, α-Fe_2O_3, and ZnO nanoparticles. As Nath D., Banerjee P., and Das B. (2014) [1] discussed, chitosan-based nanoparticles have the advantages of improved efficacy, reduced toxicity, and improved patient

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compliance over standard preparations. As B. R. Thimmaiah and Nallahami (2020) [2] revealed, α-Fe_2O_3 can be synthesized by the co-precipitation method by ferric and ferrous salts. Hence, KOH helps as a precipitation agent. The research of Abdo A. M. et al. (2022) [3] indicates green synthesized ZnO nanoparticles are versatile and used for antimicrobial activity against clinical pathogens. Maijan P. et al. (2024) [4] demonstrated ZnO can also be synthesized by green method by using agricultural waste. Silver (Ag) nanoparticles can be synthesized using chitosan as a reducing agent.

The major concern of green nanotechnology is ensuring sustainability by improving innovative technology, recycling technology, decarbonization technology, and green energy production. It has a significant role in mitigating climatic changes and reducing greenhouse gases.

Green nanotechnology has a variety of applications, such as nanobiotechnology, nanomedicine, environmental remediation, recycling nanomaterials, and waste treatment. In the energy sector, green nanotechnology is targeted toward replacing burning coal, charcoal, and fuels with non-smoky, pure, suitable, and secure energy. As the research of R. Kumar et al. (2020) [5] indicates nanotechnology, particularly CNT Nanofluids, has a great role in CO_2 capture processes.

Green synthesized nanoparticles have been used for wastewater treatment and environmental remediation. Wastewater has several environmental and health impacts. There are three types of wastewater or sewage. These are domestic sewage, industrial sewage, and storm sewage. This sewage disrupts the surroundings by causing pollution. Previously, coagulation, flocculation, hydrolysis, and fermentation have been used to treat wastewater. In the contemporary world, developments in nanotechnology enable an efficient way of wastewater treatment. Green nanoparticles have been seen as an efficient method of wastewater treatment. This research is aimed at investigating the principal role of green nanotechnology in wastewater treatment and environmental remediation. The research presents better methods of wastewater treatment by generating clean energy.

WHY DOES GREEN NANOTECHNOLOGY PRESENT A BETTER TREATMENT?

Various Sustainable Development Goals, such as poverty eradication, healthcare and well-being, clean water supply, sanitation, and affordable and sustainable energy incorporate Green Nanotechnology. Developing countries, like most African countries, will benefit greatly from nanotechnology. Although industrialization, civilizations, and technology are rapidly growing from time to time, the world’s waste dosage is increasing in proportion to the size and development in technology.

Green nanoparticles or polymer nanoparticles, such as chitosan nanoparticles help to increase the velocity and dewater the sludge by forming a solid-liquid state. Chitosan nanoparticles are good biosorbents and are hence used to remove chemicals, such as dyes from wastewater. As M. M. Naim et al. (2017) [6] revealed, green nanoparticles play photocatalytic activity, increase the absorption rate due to high surface area to volume ratio, and engulf microorganisms. Some metal nanoparticles, such as silver (Ag) NPs influence the sorption properties. Hence, Ag NPs are used for dye effluent, removal of bacteria, and degradation of wastewater into hydrogen, oxygen, biogas, etc.

Green nanotechnology is an efficient method of industrial wastewater treatment. Green nanotechnology provides a means to convert organic, microbial, and polymer waste into useful energy forms. Wastewater discharged from the chemical industry, dairy industry, and polymer must be charged to reaction chambers with green nanoparticles. This research is, therefore, aimed at investigating the potential of green nanotechnology in wastewater treatment discharged from chemical industries. The treatment process undergoes flexible and amendable procedures as follows:

1. Observation, diagnosis, and identification of microorganisms in the contaminated (waste) water in the surroundings.
2. Production of stable, biocompatible, biodegradable, and eco-friendly green nanoparticles which fasten degradation of bio waste, kill microorganisms, and generate pure water and H_2.

3. Incorporating green nanoparticles, nanomembrane, and nano absorber for purifying the wastewater.
4. Isolating carbonaceous products, recovering, recycling, and reusing them for further application from the end product. Wastewater treatment involves removing toxins, recycling, and recovering wastewater.
5. Evaluating the sustainability, effectiveness, environmental fate, and health risk effects of green nanoparticles
6. Establishing control and monitoring systems for the production of bioenergy, green hydrogen, blue hydrogen, and wastewater treatment procedures.
7. Establishing a policy for the end use of such technology and opening an extension program to induce a constructive attitude toward the global role of green nanotechnology.

What advantages does green nanotechnology offer? Research into environmental protection and wastewater treatment is an ongoing process. Green nanotechnology is ever-growing and targeted toward bio-conservations, fostering suitability, and creating an eco-friendly ecosystem. Moreover, cellulose nanocrystals and nanofibrils are strong absorbers of contaminants and pollutants from wastewater. Green nanoparticles have the capacity to generate heat energy which speeds up the breakdown of wastewater into separate counterparts.

Green nanoparticles enable heavy metal removal, and dehydration of wastewater, and serve as nanoabsorbant. Fernando D. Guerra et al. (2018) [7] verified that polymer/inorganic hybrid nanomaterials have adsorptive capacity, and help to remove toxic metal ions, dyes, and microorganisms from wastewater. The following is the green nanotechnology-based approach one can treat wastewater for different purposes (Figure 1).

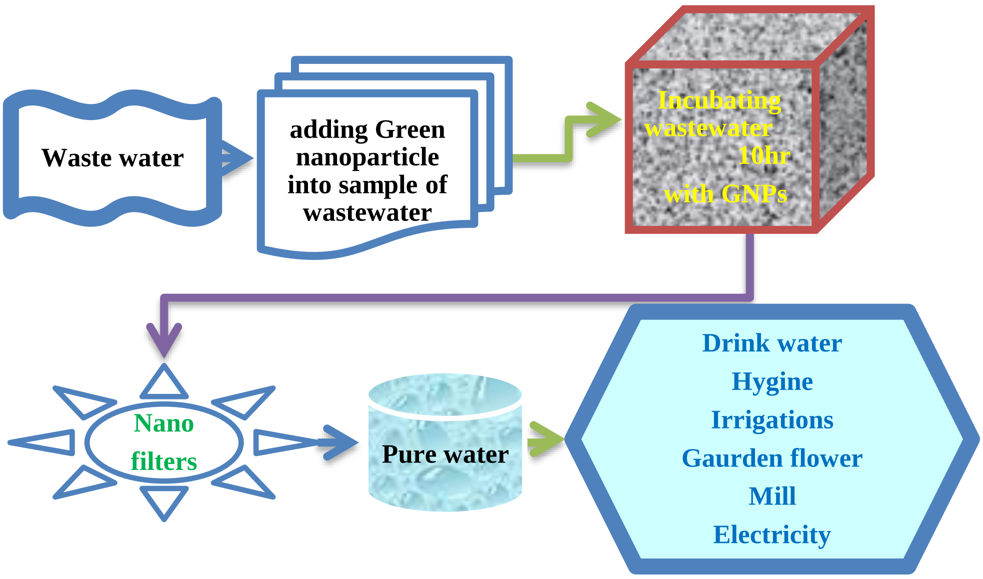

Figure 1. Green nanotechnology for wastewater treatment.

Green nanoparticles are used for detecting, neutralizing, and treating wastewater. Green nanoparticles serve as enzymes, absorbents, and oxidizing agents. ZnO nanoparticles are also used for the removal of phenol and dyes from wastewater. As demonstrated in Figure 2, incubating the wastewater with green nanoparticles (GNPs) for about 10 hrs. enables the reduction of microbial since nanoparticles engulf and kill microorganisms. Besides, nano filters must be installed to remove residue chemicals, viruses, organic molecules, and ionic salts (KOH), and help to harden water.

1. Green nanoparticles synthesized by biological methods/ Green synthesis method must be tested and proven its quality and reliability.
2. The sampled wastewater is marked in various sources and stored in a certain container.
3. Green nanoparticles are then allowed to react with wastewater.
4. They are then incubated for up to 2 days depending on the type, nature, and external stimuli/type of enzyme used to speed up the rate of chemical reactions.
5. The container relates to a nanomembrane filter and hydrogen container, and providing a pressure of gas supplies, hydrogen is collected into the hydrogen container.
6. Alternative to step 4, the wastewater is electrolyzed by electric potential of order 220–500kV. Then the electrode is connected to a hydrogen container.
7. Then quality measurement must be undertaken to ensure reliability and health risk effects.

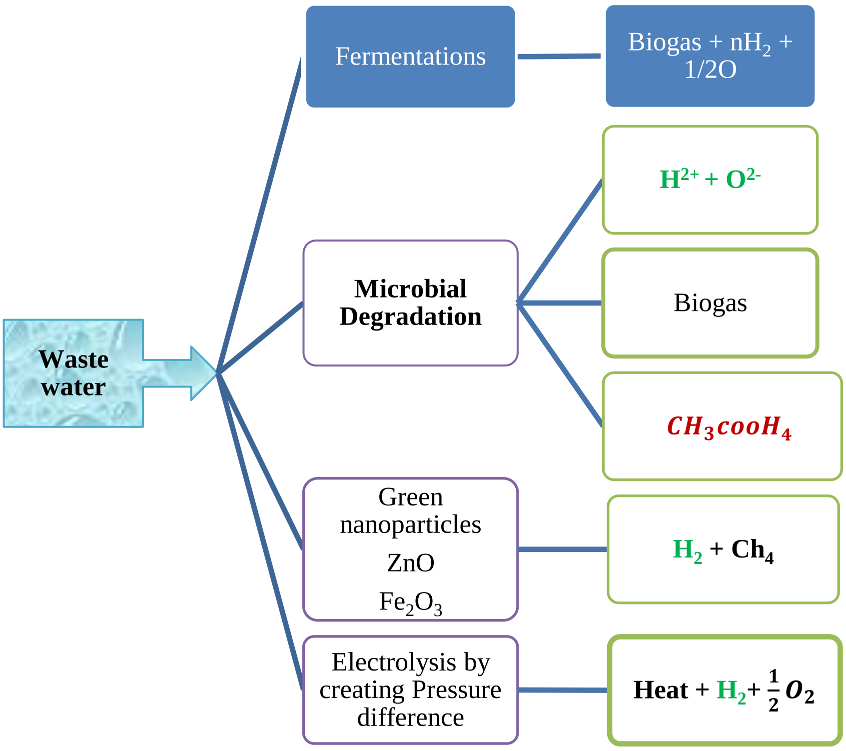

Figure 2. Wastewater treatment using green nanotechnology.

It is also important to note that all fermentations, electrolysis, and microbial methods do not produce pure water directly. They produce hydrogen, oxygen, and other products, such as methane, acetic acid, biogas, etc. However, hydrogen and oxygen must be extracted and kept in a closed-loop system and undergo further chemical reactions to yield pure water. Even this water must be tested by sensors, radars, or bio detectors before drinking. Green nanoparticles, such as ZnO and Fe_2O_3-based magnetic sensors and optical sensors can assist in such tasks.

The research of Sumira Malik et al. (2022) [8] shows that iron nanoparticles extracted from ageratum conyzoide can help treat wastewater. M. M. Berekaa (2016) [9] revealed quantum dots and dye-doped nanoparticles are used for detecting microbiological organisms from wastewater. Jebin Ahmed et al. (2021) [10] also discussed the potential applications of adsorbents, like silicon, carbon, kaolin, and polymers for the removal of wastes, such as Azo dyes generated by the textile industry. Silicon nanoparticles are also nanoabsorbants of bacteria, heavy metals organic pollutants. Coagulation is another important wastewater treatment technique. Coagulates tend to produce non-equilibration and remove charge instability. However, if the pollutants have opposite charges they form electrostatic equilibrium forming neutralization and helping to purify wastewater.

Green nanoparticles enable generations of bioenergy and green hydrogen which can replace gasoline and diesel. Khoo S. K. et al. (2022) [11] reported, that bioenergy can be produced by optimization of lignocelluloses, microalgae, and wastewater. Green nanoparticles can absorb solar energy and help to break the bond between hydrogen and carbonyl. The light absorbed is required to dissociate the bond between microbial/organic compounds.

Nanocomposite has found applications in industrial wastewater treatment. Compared to other metal nanoparticles, Iron nanoparticles are less harmful to the environment. It has less cost and is used for groundwater remediation. More specifically, the composite of graphene iron oxide ($G–Fe_2O_3$) nanocomposite is used for both adsorbent and removal of heavy metals from wastewater. As the research of Thangavelu L. (2022) [12] shows, graphene-iron oxide nanocomposite is detected for the elimination of hazardous chemicals like phenazopyridine from wastewater. Aluminum sulfate $Al_2(SO_4)_3$ is another nanomaterial that has been used in wastewater treatment.

PRESSURE ENHANCED ELECTROLYSIS

Electrolysis is another method of treating waste. It is quite applicable for wastewater treatment. It is a mechanism used to dissociate wastewater molecules into hydrogen and oxygen by making a potential difference. This mechanism is an alternative means of harnessing sustainable energy, such as green hydrogen. To increase the rate of degradation, the electrolysis process is accelerated by the pressure of gas supplies. Kumar, V. (2017) [13] has demonstrated the impact of current density, electrode types, and time of electric current application on wastewater treatment. It is proven as an efficient method of waste removal and treatment.

Wastewater is being negatively charged. Hence, green nanoparticles must be charged positively and stabilize electric current flow with a current density (J) up flow duct. The relation between pressure, potential difference, electric current density, and speed of the sample of mass is related by

$$P - P_a = \frac{2gJ\Delta V}{\vec{V}^2} \tag{1}$$

where, $P_a = 1.013 \ x \ 10^5 Pa$ atmospheric pressure at sea level, P – is the system pressure, J – is the electric current density, ΔV – is the potential difference, $\vec{V}$ – is the average molecular speed. Taking the molecular speed, 20m/s, ΔV = 360 V, then, the change in pressure is

$$\Delta P = \xi \vec{J} \tag{2}$$

where, $\xi = 18Kg\,\frac{m^3}{cs^4}$ is constant of proportionality which describes the electric charge interaction with matter. Hence, $\Delta P \sim J$, $\Delta P \sim \Delta V$, and $\Delta P \sim \frac{1}{\vec{V}^2{}_{mol}}$.

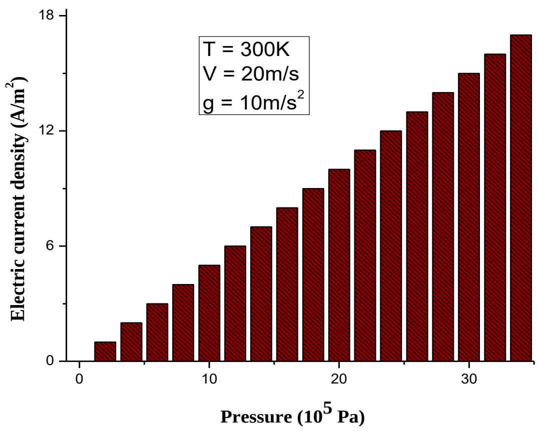

Figure 3. The relation between pressure and electric current density in the electrolysis process.

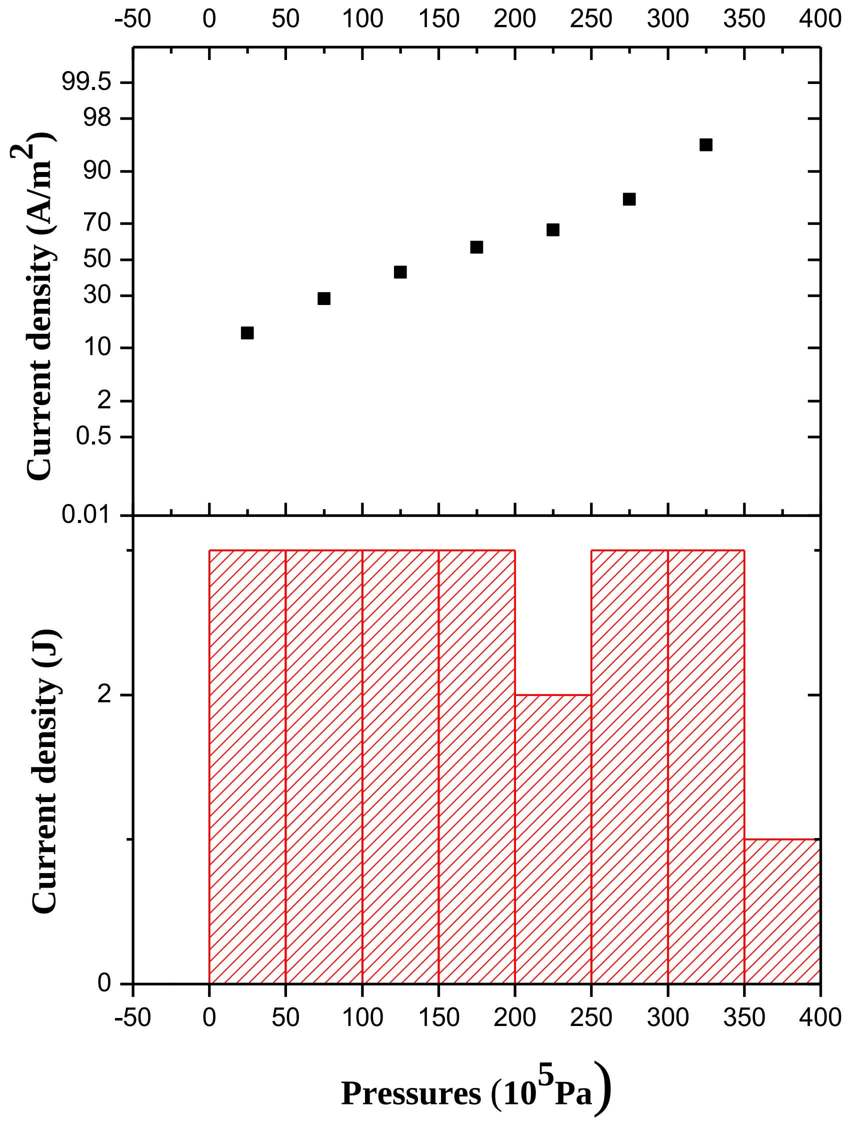

Figure 4. The probabilistic values of current density (J) count against pressure difference (ΔP).

However, by making a pressure difference $\Delta P = P - P_a$, it is possible to control its states and direction of flow. As shown in Figures 3 and 4, the difference in pressure increases with the increase in electric current density. This technology enables not only wastewater treatment but also serves as a way of producing green hydrogen through electrolysis of water using electricity from renewable sources which adds to our global energy economy. This principle is applicable in nanomembrane filtrations which are presented in the subsequent sections.

NANOMEMBRANE FILTRATION

Nanomembrane filtration is a pressure-driven filtration. It is used in softening water, brackish water treatment, industrial wastewater treatment and reuse, product separation in the industry, salt recovery, and desalination.

1. Removing organic waste and microbial wastes are challenges and should be treated using nano absorptions/nano membrane filtration techniques.

2. Green hydrogen-based green nanotechnology is not only nanowaste treatment technology but also recycling technology. Therefore, designing recycling technologies on the principal operational, and processing mechanism of green hydrogen-based green hydrogen is greatly encouraged since metal nanoparticles, semiconductor nanoparticles, and carbon nanoparticles, can be extracted by recycling nanowaste.
3. Electrolysis/thermo electrolysis of waste is important since electrolysis of nanowaste/organic waste, like wastewater and biopolymers, results in the generation of electricity, fuels, green hydrogen, and pure water where green hydrogen appears as eco-friendly bioenergy. Fabricating and designing devices that produce internal surface pressure as smart flower technology protects sensitive electronic appliances, such as sensors, actuators, motors generators nanowaste, and dust particles.
4. To protect the environmental fate and pollution, nanoabsorbant should be integrated with this technology to absorb Nano residues for further recycling.
5. Integrating turbidity sensors is encouraged to determine the number of suspended solids while infrared radar is installed for water supply and rescue operations.

To generalize green nanotechnology can be regarded as Greenpeace environmental trust and commission. Green nanotechnology is an alternative way of reducing waste, water treatment, and recycling materials. It is the most cost effective and environmentally friendly technology fostering environmental remediation, sustainable energy, sustainable economy, and sustainable development. Green nanotechnology offers not only wastewater treatment and environmental remediation but also fosters sustainability by reducing greenhouse gases and preventing global warming. Herein, the introduction of green nanoparticles in waste treatment and pollution control helps the system serve as the selective killer of microorganisms, air borne diseases, and reduce waterborne diseases. Hence, it ensures sustainable health.

CONCLUSIONS

In this research, the potential role of green nanotechnology in ensuring environment remediation and wastewater treatment is envisioned. Green nanotechnology is an effective means of treating wastewater discharged from chemical, industries, contaminated water, plastic industries, and polymer industries. This is because nanotechnology enables the green synthesis of nanosized materials, like green nanoparticles, nanocomposite, and carbon nanotubes, which are both eco-friendly and solutions to the environmental hazards.

These technologies are dependent on environmental conditions, the kind of industries, water compositions, and the type of water needed. Green nanotechnology enables the removal of heavy metal ions by splitting nanowaste into free radicals and elements. It ensures zero carbon emission by converting wastewater into useful energy forms like bioenergy and green hydrogen.

Green nanotechnology fosters sustainability by enabling pressure-enhanced electrolysis, green hydrogen production, and wastewater treatment. The electrolysis process enhanced by pressure is another means of wastewater treatment which in turn accelerates green hydrogen & bioenergy production. In the future, green nanotechnology is expected to replace existing bioenergy conversion systems and widen the opportunity to utilize bioenergy for industrial and household applications.

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