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Plant Extract-Based Silver Nanoparticle Synthesis, Characterization, and Removal of Dye from Wastewater

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ABSTRACT

The fast expansion of industrial zones, particularly in the textile sector, has resulted in higher production rates and the formation of dye-laden wastewater, creating substantial environmental and health problems. Silver nanoparticles (AgNPs) manufactured utilizing green technologies and plant extracts have emerged as a viable wastewater treatment solution. This technique uses AgNPs' distinctive features, such as high surface area and catalytic activity, to break down hazardous dyes via adsorption and photocatalytic reactions. Plant extracts replace hazardous chemicals as environmentally acceptable reducing and stabilizing agents. Several techniques are used for the characterization of AgNPs such as SEM, TEM, EDX, etc to confirm the synthesis of nanoparticles and functional properties. AgNPs are used in many applications including wastewater treatment, anti-bacterial and antifungal treatment. However, some challenges need to be addressed regarding the toxicity of Ag ions after wastewater treatment. This article presents the synthesis, characterization, mechanism of dye removal, and applications of plant extract-based AgNPs.

Keywords: Wastewater, Silver nanoparticles, Dye, Plant extract

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Introduction

More comfort and convenience of living have led to the growth of industrial zones in this highly developed and populous era, and the demands of the populace are driving an increase in production rates daily. Due to the necessity of clothes and fluctuating fashion, several textile industries, such as weaving, leather, finishing, and dying, require various chemicals and dyes in their production. The untreated disposal of wastewater produced during production and processing causes numerous environmental issues for aquatic life and humans. One of the main categories of contaminants found in wastewater is dyes [1]. As textile effluent containing dispersed dyes has a high potential for causing cancer, mutagenesis, or teratogenicity in humans, its release into the environment has significant risks. According to the World Bank, the textile industry accounts for 20% of global industrial water pollution [2].

As a result of advancements in nanotechnology, silver nanoparticles have been effectively employed in wastewater treatment. Because of their unique traits such as a larger surface area and smaller size, dispersion, and morphology new uses for nanomaterials are developing quickly. These properties provide nanoparticles with unique intrinsic qualities that make them highly suitable for use in catalytic dye degradation [3]. To prepare nanoparticles, three important needs must be met: a safe stabilizing chemical, an effective reducing agent, and an environmentally friendly solvent [4]. Silver salt has been treated using a variety of synthetic techniques, including chemical, photochemical, and electrochemical processes, to develop silver nanoparticles (AgNPs). However, these techniques cause significant environmental damage and need for the employment of hazardous chemicals and extreme reaction conditions. A new technique for manufacturing AgNPs using plant extracts has been introduced as a result of the drawbacks of the previously described methods. The synthesis of nanoparticles mediated by plant extract modifies their size distribution, shape, and size. Compared to other documented physiochemical approaches, the biological method for nanoparticle synthesis has several advantages, including the use of water as a non-toxic solvent, the avoidance of hazardous or toxic compounds, gentle reaction conditions, and cost-effectiveness [5]. The plants supply stabilizing and reducing agents, eliminating the need for costly and hazardous chemicals. Plant extracts are readily available, safe to handle, promote healthier communities and workplaces, result in safer products and less waste, and contain a wide variety of active compounds that promote the reduction of metal ions [6]. Plant components such as leaves, stems, roots, bark, seeds, fruit, pulp, peels, flowers, and plant nectar (honey) provide a superior platform for the production of certain phytochemicals needed to fabricate nanoparticles [7]. In upcoming sections, we will get to know about the synthesis, characterization, mechanism, and applications of silver nanoparticles using plant extracts.

Synthesis and Characterization of AgNPs

Plant parts such as leaves, roots, flowers, fruits, and rhizomes have all been efficiently utilized to develop AgNPs. To get rid of trash and other unwanted materials, various plant components are collected from various sources, properly cleansed with ordinary water, and then distilled. The pieces are either used fresh to make an extract or dried and ground into powder. In order to make the extract, the crushed powder of plant parts is mixed with deionized water or alcohol and usually heated for a few hours below 60 °C, because prolonged high-temperature heating can break down the phytochemicals in the biomass extract. Plant extract of varying pH is added to the solutions with a different concentration of Ag salt as a metal precursor, followed by heating at different temperatures leading to the synthesis of AgNPs [8].

Visual observation confirms the synthesis of AgNPs the bacterial reduction of Ag^+ ions to AgNPs was made by observing the reaction mixture's color shift from pale yellow to dark brown [9]. Ultra Violet-visible spectrum analysis was used to identify the produced AgNPs' surface plasmon resonance [10]. Fourier Transform Infrared spectroscopy (FT-IR) assists in determining the kind of functional group and chemical bonding present in either organic or inorganic materials [11]. The morphological structure and element composition content were assessed using a Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), and Energy-Dispersive X-ray analysis (EDX) data [12] X-ray Photon Spectroscopy (XPS) is used to study the elemental constituents, surface chemistry, and their electrical configuration [13].

Mechanism of Dye degradation using AgNPs

The broad-spectrum techniques of dye removal with AgNPs include adsorption onto activated carbon-containing silver nanoparticles, photocatalytic degradation, or a combination of both. In adsorption, activated carbon coated with silver nanoparticles demonstrated the highest adsorption of 71.4 mg of methylene blue/g of adsorbent. At an initial concentration of 50 mg/L, dyes such as Congo red, Eosin yellow, Bromophenol blue 2, and brilliant blue showed 99% dye removal following adsorption utilizing nano-silica powder made with AgNPs. However, acetone-based desorption tests produced an 86% dye desorption rate [14] .

In photocatalytic degradation, the ability of spherical (8–32 nm) AgNPs is produced using a green approach to degrade dyes. In ten minutes, a 100% reduction in the harmful Methylene Blue dye was seen. When methylene blue dye is catalyzed to degrade, the colloidal AgNP formulation facilitates electron transport. Research has shown that AgNPs absorb solar light's visible spectrum and excite the surface electron to a higher energy state. Additionally, hydroxyl ions and oxygen molecules take up the excited electron to create radicals, which aid in the breakdown of dye molecules that are absorbed on the surface of AgNP. The dye's electron is taken up by the hole made on the AgNP orbital, aiding in the dye's further degradation [15] .

Applications and Limitations of AgNPs

Plant extract-mediated green synthesis of silver nanoparticles can be used for water treatment. Examples of methods for detoxifying water and wastewater include adsorption, photo-catalytic degradation, and nano-filtration employing nanoparticles [16]. As an antibacterial activity, plant extracts in the synthesis of AgNPs provide an attractive strategy to produce alternative anti-bacterial agents that can kill drug-resistant pathogens [17]. AgNPs are also used as antifungal agents against *Fusarium oxysporum* [18]. The use of AgNPs for textile dyeing, wastewater treatment, and the removal of harmful contaminants purposefully introduces or discharges manufactured or designed AgNPs into aquatic or terrestrial environments. After being discharged into the environment, AgNPs split into Ag ions when the habitat's thermodynamic conditions allow for their dissolution; these Ag ions are more harmful to biological systems than AgNPs [19].

Conclusion and Perspectives

Green synthesis of silver nanoparticles is a versatile method for treating dye effluents.

Particular attention is paid to the elimination of dyes that are frequently used in the textile industry while discussing the important mechanism of silver nanoparticles in the treatment of dye pollutants, including photocatalytic degradation and adsorption. Using plant extracts showed that the effective shrug off different dyes from wastewater is demonstrated by using environmentally friendly and less toxic reducing agents in producing silver nanoparticles. However, there may be many barriers before nanoparticles may be used for large-scale applications, although they appear to provide many potential benefits for water treatment and purification. To properly understand their potential, several studies are necessary to control these barriers by organizing appropriate conversions of silver nanoparticles.

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