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ECO-FRIENDLY SYNTHESIS AND APPLICATION OF SILVER NANOPARTICLES IN WATER TREATMENT TECHNOLOGIES

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ABSTRACT

An environmentally acceptable approach to synthesize AgNPs from silver reclaimed from button cell batteries is investigated in this paper. UV-Vis, TEM, and antimicrobial tests were used to describe the AgNPs that were stabilized with sodium citrate and generated using sodium borohydride. The pH of the solution was then varied. Chitosan pellets were made with glutaraldehyde and glacial acetic acid, and then the best AgNPs were added to them. The efficacy of these composite pellets in treating wastewater. When compared to pure chitosan pellets, the antibacterial activity was improved by the presence of AgNPs. Using ICP-OES, the amount of silver leaching was checked and found to be within acceptable limits. The results demonstrate that composites of AgNP and chitosan have great promise as environmentally friendly and efficient wastewater treatment materials.

I. INTRODUCTION

Ensuring the availability of safe drinking water continues to rank high among the most critical issues facing the world today. Water contamination has reached alarming levels, endangering ecosystems and human health due to increasing industry, agricultural runoff, and urban trash. Although there is some effectiveness to traditional water treatment technologies, they are generally associated with secondary contamination due to their high energy consumption, complicated infrastructure, and use of dangerous chemicals. The application of metal nanoparticles in particular has given rise to nanotechnology as a potent instrument for overcoming these constraints in recent times. In particular, AgNPs have attracted a lot of interest because of the remarkable antibacterial capabilities and the possibility that they can break down a wide range of organic and inorganic pollutants. Nevertheless, traditional approaches of synthesizing AgNPs frequently incorporate harmful reducing agents and stabilizers, which give rise to worries regarding the security of the environment and human well-being. Because of this, there is a rising interest in green synthesis methods that use biological entities to make silver nanoparticles, which are benign to the environment. Green synthesis is the practice of making nanoparticles from naturally occurring substances in an eco-friendly way, typically including plant extracts, bacteria, fungus, or algae. Physical and chemical synthesis often involve the application of harmful substances; nevertheless, these biological agents can naturally reduce and cap compounds. The goal of this technique is to create functionally useful nanomaterials with little environmental impact, in line with the concepts of sustainable development and green chemistry. Because to its ease of use, low cost, quick manufacturing, and scalability, plant-mediated synthesis is very popular. Many bioactive components, including flavonoids, terpenoids, alkaloids, and phenolic acids, are found in many sections of the plant, including leaves, roots, stems, flowers, and even fruits. These compounds help reduce silver ions (Ag^{+}) into elemental silver (Ag^{0}) nanoparticles.

In addition to lowering environmental concerns, nanoparticles with improved stability, biocompatibility, and antibacterial activity are frequently produced by biological synthesis of AgNPs. Because of the importance of both efficacy and safety in water treatment applications, these characteristics are of the utmost importance. Whether in solution, embedded in membranes, or coated onto surfaces, silver nanoparticles can be used to target and eliminate a broad variety of pollutants. Bacteria, viruses, and protozoa are aquatic pathogens that cause a wide variety of infectious disorders; their potent antimicrobial action makes them ideal for this task. Also, unlike traditional treatment procedures, AgNPs have catalytic characteristics that make it easier to break down organic contaminants such as pesticides, dyes, and pharmaceutical residues. With their broad-spectrum antibacterial activity even at low concentrations, AgNPs are a great asset in water treatment. Treatment costs and hazardous residues are both reduced thanks to this feature, which drastically cuts down on the requirement for high chemical doses. There are a number of ways in which silver nanoparticles kill microbes. These include interfering with respiration and DNA replication within cells, producing reactive oxygen species (ROS), and rupturing microbial cell membranes. Traditional antibiotic and disinfectant resistance is an increasing problem, but these multi-action mechanisms make it harder for microbes to build resistance. In addition, nanoparticles' high surface area-to-volume ratio makes them more reactive and improves their contact with contaminants, which in turn makes them more effective in adsorption and degradation.

In spite of these benefits, there are a number of safety and environmental problems with using AgNPs to treat water. These include the possibility that they are hazardous to species that aren't intended targets and the persistence of nanoparticles in the treated water. Given these challenges, it is critical to regulate the synthesis of nanoparticles with respect to their size, shape, concentration, and surface characteristics. By including biogenic stabilizers into the synthesis process, which naturally encase the nanoparticles and forestall their undesirable aggregation, green synthesis techniques provide superior control over these parameters. Furthermore, researchers may optimize the synthesis conditions and select suitable biological sources to customize the features of AgNPs for specific water treatment demands with low environmental effect.

Research into composite materials and sophisticated filtering systems that include green-synthesized AgNPs is another exciting field. One way to improve the filtration efficiency and antibacterial characteristics of materials like zeolites, polymeric membranes, or activated carbon is to insert silver nanoparticles into them. Improved contaminant removal is achieved by combining the physical filtering characteristics of the base material with the functional activity of AgNPs in these hybrid materials. By offering accessible and effective solutions for populations lacking centralized infrastructure, such low-cost and portable technologies have the potential to revolutionize water purification in decentralized and rural settings.

II. REVIEW OF LITERATURE

Plesnicute, Ramona et al., (2025) Industrial manufacturing on a global scale produces hundreds of tons of silver nanoparticles every year. These particles have a wide range of applications in industries such as cosmetics, hygiene, textiles, optoelectronics, photovoltaics, and more. Eventually, they are released into the environment, where they damage the biosphere in an unpredictable way. An eco-friendlier method of synthesis might be used by substituting natural antioxidants for chemical reductants of silver. This would make the process more sustainable and less harmful to the environment. In an effort to provide antimicrobial solutions with a lower environmental effect through sustainable green-chemistry, we produced silver nanoparticles using plant extracts. To guarantee ionic silver reduction and silver nanoparticle synthesis in colloidal suspensions, the natural antioxidants used were extracted from fresh lemon pulp, blueberries, and blackberries, as well as from dried green tea leaves. Dynamic light scattering, X-ray diffractometry, dark field optical microscopy, scanning electron microscopy, and ultraviolet-visible spectrophotometry were used to analyze the four samples. These techniques revealed that the samples exhibited plasmonic characteristics, standard crystallinity, particular fine granularity, and excellent stability in water suspension. Efficacy against two common bacteria, Staphylococcus aureus and Escherichia coli, was evaluated by means of the agar diffusion method and the bacterium kill-time approach. Though all of the silver nanoparticles demonstrated adequate performance in both experiments, the green tea-based sample outperformed the control group due to its higher overall antioxidant activity and higher concentrations of polyphenols and flavones. Such silver nanoparticles might provide the basis for a wide range of applications that promote sustainable chemistry.

Kalakonda, Parvathalu et al., (2024) An aqueous extract of Terminalia chebula fruits was utilized to synthesize AgNPs. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to analyze crystalline AgNPs ranging in size from 21 to 24 nm. Similar to T-Chebula-AgNPs (TC-AgNPs), the biosynthesized AgNPs exhibited a band gap energy of 2.8 eV and an average size of 50 nm. An examination of antimicrobial properties against Escherichia coli (E. coli) was conducted to demonstrate the antibacterial activity of AgNPs.

The results were compared to the common antibiotic gentamicin. A greater zone of inhibition was seen as the concentration of TC-AgNPs increased, demonstrating the effectiveness of these nanoparticles. T-Chebula extract alone, on the other hand, was ineffective against bacteria. In comparison to earlier research, TC-AgNPs demonstrated a 92% dye degradation rate when exposed to visible light, demonstrating their strong catalytic potential in the degradation of water-soluble commercial methylene (MB) dyes. Notably, TC-AgNPs maintained their stability and recyclability across all three rounds. There is great promise for biogenically produced TC-AgNPs in the degradation of organic contaminants and the deactivation of microbes. These results demonstrate their potential for photodegradation of organic pollutants and microbial control, two areas where they are needed for long-term environmental clean-up.

Krishna et al., (2024) The fascinating properties of nanoscale materials and their size-dependent effects make nanotechnology an intriguing field with enormous promise for applications in biology. Recently, there has been a lot of interest in metal nanoparticles, particularly silver, due to their remarkable optical, electrical, and antibacterial properties. The attractiveness of silver nanoparticles (AgNPs) as a research subject stems from their abundance in the earth's crust and their relative affordability. This comprehensive review delves deeply into the relevance of silver nanoparticles in environmental remediation and stresses its crucial efficacy in tackling environmental challenges. New approaches to the effective removal of contaminants are being created by capitalizing on the unique qualities of AgNPs, such as their catalytic and antibacterial capabilities. The review delves into the numerous uses and encouraging results of silver nanoparticles, analyzing their revolutionary potential and how they might improve environmental clean-up methods. In their role as environmental protectors, the authors of this study call for more research into and use of silver nanoparticles. This review also intends to help researchers in the future create innovations using AgNPs carrying nanoprobes that are more efficient and cost-effective. With their low limit of detection (LOD) and dependable repeatability, these nanoprobes may potentially detect many groups of pollutants all at once. The plan is to use these inventions to clean up polluted areas.

Hayder, Nadhem et al., (2020) This work set out to biosynthesize silver nanoparticles by employing a rhaminolipid as a reducing and stabilizing agent, derived from a local strain of Pseudomonas aeruginosa. Several fields have found uses for silver nanoparticles (AgNPs) produced using environmentally friendly methods, including medicine, cancer research, biosensing, catalysis, and more. The biosurfactant contains mono- and di-rhamnolipids, with Rf values of 0.86 and 0.36, respectively, according to a thin-layer chromatography (TLC) characterisation study of the pure bio emulsifier. The results of optimizing the biosynthesis of silver nanoparticles revealed that the Surface Plasmon Resonance (SPR) bands of the nanoparticles were more intense as the wavelength was changed from 200 to 400 nanometers. Furthermore, the optimal circumstances for creating AgNPs were as follows: a pH of 5, a temperature of 40°C, a reaction time of 5 minutes, a concentration of 2×10-3 w/v rhaminolipid as a reducing agent, and a concentration of 6×10-3 mol/L silver ions. The silver nanoparticles had a size of 38 nm and a somewhat steady peak at -23.2 mV, as shown by the X-ray diffraction measurements. Finally, the minimum inhibitory concentration against human-harming gram-negative and gram-positive bacteria was determined to be 1 mg/ml of Ag NPs. The test animals who were administered AgNPs showed complete healing of their infections after 6 days of therapy, in contrast to the control group that was given fucidin. This suggests that the anti-inflammatory effects of the AgNPs were effective.

III. MATERIAL AND METHODS

Materials utilized

Sodium borohydride, hydrochloric acid, sodium hydroxide, and sodium citrate were utilized in the production of AgNPs, as previously reported, in order to create silver nitrate from silver that was recovered from button cell batteries. High molecular weight chitosan, 100% glacial acetic acid, and 50% weight-to-volume glutaraldehyde were used to make chitosan pellets. Everything was used exactly as it was given to it. Deionized water was used to prepare all of the solutions.

Stainless steel cutlery is one of the industries that uses the Farroupilha wastewater treatment plant, where the sample was collected. The raw wastewater was detailed in a previous research. To eliminate organic substances, a biological treatment tank was utilized to mix the water used to clean the gas scrubber and kitchen with sanitary effluent. The water underwent further treatment to eliminate particulates following a physical-chemical treatment. The last stage was to mix the water with rainwater and store it in a reservoir.

Methods

We produced AgNPs at several pH levels and tested the solutions for antibacterial, UV-Vis, and transmission electron microscopy characteristics. The next step in making pellets was to combine chitosan with the best AgNPs solution. The pellets' antibacterial capabilities were also assessed. The antibacterial capabilities of chitosan were tested by comparing pellets of pure chitosan with those of pellets containing AgNPs. The disinfection of industrial wastewater was assessed by testing for the presence of Escherichia coli using the Petrifilm 3M® assay. The wastewater was treated with chitosan pellets that contained AgNPs. The bactericidal or bacteriostatic effects of the chitosan-containing AgNP pellet treatment on Escherichia coli were tested by doing the same treatment in a solution containing only this organism. The study's approach is illustrated schematically in Figure 1.

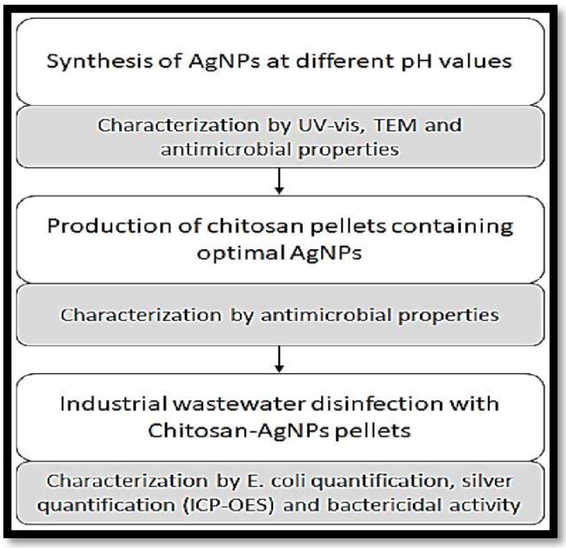

Figure 1. Figure showingproposed methodology of the study.

Wastewater Disinfection

At room temperature, 50 chitosan-containing AgNPs pellets were stirred with 150.0 mL of wastewater for 60, 120, and 180 minutes as part of the industrial wastewater disinfection operation. The experiment was repeated twice using a shaker incubator set to 150 rpm of stirring speed. Using Petrifilm 3M® and procedure 991.14, which is recommended by the Association of Official Analytical Chemists, we were able to quantify Escherichia coli by collecting a tiny sample of wastewater (approximately 1.0 mL) before and after each period.

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

After 180 minutes, the amount of silver leached in the wastewater disinfection process was measured using inductively coupled plasma optical emission spectroscopy (ICP-OES) and the Standard Methods 3120B for Examination of Water and Wastewater. This was done with both the raw effluent and a portion of the treated wastewater.

IV. RESULT AND DISCUSSION

Industrial Wastewater Disinfection

Before and after treating the wastewater with the chitosan pellets containing AgNPs, the values of the Escherichia coli quantification are shown in Table 1.

Table 1. Escherichia coli (CFU/mL) Count in Raw and Treated Wastewater Using AgNP-Chitosan Pellets

	Assay 1	**Assay 2**
Raw wastewater	8.2 × 102	7.6 × 102
60 min of treatment	<LQ *	<LQ
120 min of treatment	<LQ	<LQ
180 min of treatment	<LQ	<LQ

Note: * LQ = limit of quantification (1.0 CFU).

Chitosan pellets with AgNPs had strong antibacterial activity, eliminating Escherichia coli from industrial effluent after 60 min. Authors have claimed success treating industrial wastewaters with hybrid materials. These works often prepare hybrids using AgNPs. After 60 min of treatment using grape pomace extract-derived chitosan pellets with AgNPs, industrial effluent Escherichia coli count dropped 47%. Another study treated industrial wastewater with thin films of PAH and PAA containing AgNPs and found a 90% decrease in Escherichia coli after 360 min. Silver leached into the medium increased the decrease to 93% in a second treatment cycle. After 90 min of treating industrial wastewater using montmorillonite, alginate, and AgNPs hybrids, total coliforms dropped 98.5%.

Table 2 shows leached silver concentrations in wastewater before and after 180 min. Silver was only found in one test repeat.

Table 2. Silver Concentration (mg/L) in Raw and Treated Wastewater Using AgNP-Chitosan Pellets Measured by ICP-OES

	Assay 1	Assay 2
Raw wastewater	<LQ *	<LQ
180 min of treatment	<LQ	0.0113

Note: * LQ = limit of quantification (0.0093 mg mL−1).

The WHO recommends a reference value of 0.1 mg L−1 for silver content in drinking water, which does not represent a health concern. The test leached approximately 10 times less silver than the reference value, hence it did not pose health hazards.

<u>Bactericidal Activity of Chitosan and AgNPs Pellets</u>

Chitosan pellets with AgNPs were tested for bactericidal action, as shown in Figure 2. Escherichia coli did not grow in Petri dishes following disinfection with chitosan pellets containing AgNPs.

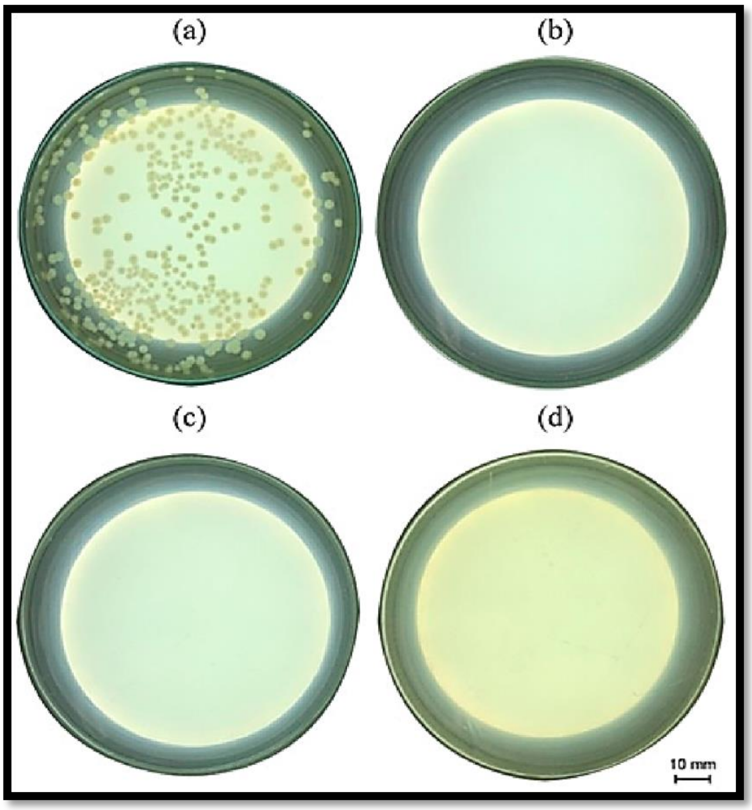

Figure 2. Evaluation of the bactericidal activity of chitosan pellets containing AgNPs against Escherichia coli: (a) control; (b) 60 min of treatment; (c) 120 min of treatment; (d) 180 min of treatment.

This stage showed that chitosan pellets containing AgNPs treated wastewater and killed Escherichia coli after 60 min.

V. CONCLUSION

This study demonstrated a sustainable and effective method for synthesizing silver nanoparticles using recycled silver from button cell batteries. When combined with chitosan to form pellets, these nanoparticles showed strong antibacterial activity, particularly against E. coli, making them highly effective for disinfecting industrial wastewater. The use of natural and eco-friendly materials, along with minimal silver leaching, highlights the environmental safety and practicality of this approach. Overall, the findings support the potential of AgNP-chitosan composites as a promising solution for cleaner water treatment technologies.

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