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Silver nanoparticles in water treatment: a review on Synthesis, Applications and Mode of Action

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ABSTRACT

Silver nanoparticles have emerged as a promising disinfectant in recent years due to their unique properties and effectiveness against a wide range of microorganisms. The use of silver nanoparticles as disinfectants is gaining popularity in various fields, including healthcare, food industry, and water treatment. It shown to have excellent antimicrobial properties and can be used to kill bacteria and viruses in water. These nanoparticles can be used in various forms, including as coatings on surfaces or as additives in water treatment plants. The use of silver nanoparticles has been shown to be effective in reducing microbial growth in water systems and improving the quality of drinking water. This review article describes various applications of Silver nano-material against a variety of water pollutants and also emphasizes on the study of various methods of synthesis and its mode of action.

Keywords*: *Antimicrobial activity, Mode of action, Silver nanoparticles, Synthesis, Water treatment

1. Introduction

Water is an essential resource for all living organisms, and the quality of water is crucial for human health and the environment. However, the increasing population and industrialization have led to the contamination of water with microorganisms, heavy metals, and organic pollutants. Therefore, there is a need for effective water treatment methods that can remove these contaminants and provide safe drinking water.

The sustainable growth of any civilization is in directly proportion with developing new methods for the organization of its environmental excellence. Use of Nanomaterials for water and wastewater treatment is highly efficient, modular, and multifunctional in nature, and they provide high performance, reasonable water and, wastewater treatment solutions. Numerous studies have shown that nano-materials can effectively remove various pollutants from water and wastewater thus has been successfully applied in water treatment.

Nanotechnology has emerged as a promising field for water treatment due to the unique properties of nanoparticles. These are the particles with a size range of 1-100 nanometers, and their small size and large surface area make them suitable for various applications in water treatment. In recent years, research has focused on the use of nanoparticles for water purification, including removal of pollutants, disinfection, and desalination which is the process of removing salt from seawater to produce fresh water. Graphene oxide and carbon nanotubes have been shown to be effective in removing salt from water through a process called reverse osmosis. Nanoparticles such as iron oxide, titanium dioxide, and carbon nanotubes have been effectively remove contaminants such as heavy metals, organic compounds, and also reduce Microbial growth [1] from water. Nanoparticles can be used in various forms, such as coatings on filters or membranes, as adsorbents in batch systems, or as catalysts in advanced oxidation processes.

Nanosilver particles are generally smaller than 100 nm and contain 20–15,000 silver atoms. In healthcare settings, silver nanoparticles are being used to disinfect medical equipment, surfaces, and even clothing [2]. They have been found to be effective against a range of pathogens, including multi-resistant bacterial strains such as Staphylococcus aureus and E. coli [3]. In the food industry, silver nanoparticles are being used to disinfect food contact surfaces, packaging materials, and even fresh products. Silver nanoparticles have emerged as a promising tool for water treatment due to their excellent antimicrobial properties. Silver nanoparticles have been found to be effective against a range of waterborne pathogens, including bacteria, viruses, and parasites [4]. They are being used in various water treatment technologies, including filtration systems and disinfection processes. Several studies have shown that silver nanoparticles are effective against a variety of microorganisms, including bacteria, viruses, and fungi. They have been found to be particularly effective against antibiotic-resistant strains of bacteria, which are becoming a major health concern worldwide [5].

2. Synthesis and Application of Silver Nanoparticals

Silver nanoparticles (AgNPs) have emerged as a promising nanomaterial for water treatment due to their unique physicochemical properties and antimicrobial activity. The applications of AgNPs in water treatment include disinfection, removal of heavy metals, and organic pollutants. The antimicrobial activity of AgNPs has been extensively studied and has been found to be effective against a wide range of microorganisms including bacteria, viruses, and fungi.

There are several methods for synthesizing AgNPs, including physical, chemical, and biological and green synthesis methods. Physical methods involve the use of external energy sources such as heat or radiation to reduce silver ions to AgNPs. Chemical methods involve the use of reducing agents such as sodium borohydride or citrate to convert silver ions to AgNPs. Biological methods involve the use of microorganisms or plant extracts to synthesize AgNPs.

Chemical reduction is the most commonly used method for the synthesis of AgNPs. In this method, silver ions are reduced by a reducing agent to form AgNPs. However, this method has some drawbacks such as the use of toxic chemicals and the production of hazardous waste. Green synthesis, on the other hand, involves the use of plant extracts or natural compounds as reducing agents. This method is eco-friendly and produces biocompatible AgNPs. Biological synthesis involves the use of microorganisms such as bacteria, fungi, and algae for the synthesis of AgNPs. This method is cost-effective and produces stable AgNPs. The bacterial culture was mixed with silver nitrate solution, and the mixture was incubated for 24 hours at room temperature. The formation of AgNPs was confirmed by UV-Vis spectroscopy, which showed a characteristic absorption peak at 420 nm. The size of AgNPs was determined to be in the range of 5-50 nm by TEM[6]. Plant extracts contain various bioactive compounds such as flavonoids, terpenoids, and phenolic acids that can act as reducing agents and stabilizers for AgNPs. AgNPs can be Synthesis using leaf extract of Azadirachta indica (neem) and Ocimum sanctum (holy basil). The leaf extract was mixed with silver nitrate solution, and the mixture was incubated for 24 hours at room temperature. The formation of AgNPs was confirmed by UV-Vis spectroscopy, which showed a characteristic absorption peak at 420 nm. The size of AgNPs was determined to be in the range of 10-50 nm by transmission electron microscopy [7,8]

Silver nanoparticles can be use to modify polyacrylonitrile nanofiltration membranes, enhancing their efficiency in water treatment processes[9]. The researchers developed a novel composite membrane by embedding silver nanoparticles in graphene oxide, leading to improved water purification capabilities due to the synergistic effects of both materials [10]. exfoliated Graphene oxide when modified with silver nanoparticles via a one-pot synthesis method using sodium borohydride in the presence of citric acid capping agents and utilize the prepared nanofiber membrane in the water treatment system, shows greater antibacterial activity, 30% increasing water permeability, and anti-fouling efficiency than the bare-PAN nanofiber membrane[11]. Removal of organic pollutants from water Enhanced using silver nanoparticle-decorated graphene oxide aerogels, and has great potential for advanced water treatment technologies [12].

Many studies investigate the antibacterial properties of silver nanoparticles. Silver nano-particles decorated hierarchically porous carbon materials, demonstrating their potential application in water treatment for effective removal of bacteria [13]. The biosynthesis process of silver nanoparticles was quite fast with D. bulbifera tuber extract which is rich in flavonoid, phenolics, reducing sugars, starch, diosgenin, ascorbic acid, and citric acid. The resulting silver nanoparticles were found to possess potent antibacterial activity against both Gram-negative and Gram-positive bacteria[14]. In one of the study, researchers coated silver nanoparticles onto ceramic filters and tested their ability to remove bacteria from water. The results showed that the silver-coated filters were highly effective in removing bacteria and reducing microbial growth in the water [15]. The use of silver nanoparticles investigated as an additive in water treatment plants. Researchers found that incorporation of silver nanoparticles onto the various substances significantly reduced the levels of microorganism and improved the quality of the treated water[16].

Use of magnetic biochar material with immobilized silver nanoparticles, which exhibited high efficiency in removing heavy metals and dye from water, making it a promising candidate for water treatment applications [17]. Biochar-based silver nanocomposite (Ag-nBC) using Shorea robusta leaf extract, and S. robusta leaf biochar, produced via mild thermal pyrolysis showed more than 90% removal for Congo red (CR) and Rhodamine B (RhB) dye[18].

Silver nanoparticles (AgNPs) have been used to remove organic pollutants or dyes from wastewater. Silver nanoparticle synthesise from the fresh Azadirachta indica (Neem) leaf extract and silver nitrate can efficiently removes synthetic dye such as methyl from water. This was then observed for the decolourisation and sedimentation [19]. The fabricated hybrid aerogel graphene–carbon sphere decorated with AgNPs used the reduction of anionic dye like congo red and cationic dye like methylene blue in the presence of $NaBH_4$[20]. Silver nanoparticles (AgNPs) as effective bactericidal materials are uniformly deposited on tunicate cellulose nanocrystals (TCNCs) by hydrothermal reduction of silver nitrate could efficiently separate oil/water microemulsion[21]

3. Mode of Action and Precautions for silver nanoparticals

Silver nanoparticles (AgNPs) have emerged as a promising material for water treatment due to their unique properties such as high surface area, high reactivity, and strong antibacterial activity. The mode of action of AgNPs in water treatment is complex and involves multiple mechanisms.

Several studies have demonstrated the effectiveness of AgNPs in inhibiting the growth of various bacteria, including Escherichia coli, Pseudomonas aeruginosa, and Staphylococcus aureus. AgNPs with a size of 10 nm inhibited the growth of E. coli and P. aeruginosa by 99.9% at a concentration of 10 mg/L [22]. The antimicrobial activity of silver nanoparticles is attributed to their high surface area to volume ratio, which allows them to interact with microorganisms more effectively than bulk silver. Silver ions (Ag^+) release from AgNPs are highly reactive and have a strong affinity for negatively charged surfaces such as bacterial cell walls. They disrupt the cell membrane and cause leakage of intracellular contents, leading to cell death. Ag^+ ions also inhibit bacterial enzymes and interfere with DNA replication, resulting in bacterial growth inhibition. The small size of silver nanoparticles also enables them to penetrate the cell walls of bacteria and viruses, leading to their destruction. Physical interaction between AgNPs and bacterial cells can also kill bacteria and viruses. AgNPs can penetrate the bacterial cell wall and enter the cytoplasm, where they interact with intracellular components such as proteins and DNA. This interaction can cause structural changes and functional alterations in the bacterial cell, leading to growth inhibition or cell death. A study demonstrated that AgNPs with a size of 20 nm disrupted the cell membrane of S. aureus and caused leakage of intracellular contents[23]. Silver nanoparticles could effectively inhibit the growth of E. coli, with a reduction rate of 99.9% after 30 minutes of exposure [24].
Antibacterial effect of silver nanoparticles on Escherichia coli, also explain due to the induction of a bacterial apoptosis-like response there is accumulation of reactive oxygen species which increased intracellular calcium levels, disruption of the membrane potential and DNA degradation cause silver nanoparticles an effective antimicrobial agent [25]. ROS are highly reactive molecules that can damage bacterial cell components such as proteins, lipids, and DNA. This damage can lead to growth inhibition or cell death. A study showed that AgNPs with a size of 20 nm generated ROS in E. coli and induced oxidative stress, leading to cell death[5]. Another study demonstrated that AgNPs with a size of 10 nm inhibited the growth of P. aeruginosa by generating ROS [22].

Silver nanoparticles can act as potent oxidizing agents, capable of generating reactive oxygen species (ROS) such as hydrogen peroxide and hydroxyl radicals which can react with organic and inorganic pollutants in water, leading to their degradation. Several studies have demonstrated the effectiveness of silver nanoparticles in oxidizing pollutants in water. The degradation of bisphenol A (BPA) in water using silver nanoparticles showed that silver nanoparticles could effectively degrade BPA, with a degradation rate of 94.5% after 60 minutes of exposure [26].

Silver nanoparticles can also act as effective adsorbents for pollutants in water. The high surface area and reactivity of silver nanoparticles make them capable of adsorbing a wide range of pollutants, including heavy metals, organic compounds, and dyes. The dye removal mechanism using AgNPs includes the adsorption onto AgNPs combined with loaded activated carbon or degradation through catalytic or photocatalytic methods or in combination with both [18]. In one of the study dye removal experiments were found to be spontaneous exothermic and followed Freundlich isotherm and pseudo-second order reaction kinetic model. The adsorption mechanism of Congo red involved surface complexation through specific electrostatic attraction and H-bonding, while Rhodamine B exhibited only surface complexation[18]. AgNPs with a size of 20 nm effectively removed Rhodamine B dye from water by adsorption[27] and also could effectively adsorb Methylene Blue, with a removal efficiency of 99.3% after 60 minutes of exposure[28]. AgNPs have also been found to be effective in the removal of heavy metals such as lead, cadmium, and mercury from water by the adsorption onto the surface. A studies showed that AgNPs with a size of 10 nm effectively removed Pb(II) ions from water by adsorption[29]. AgNPs have a high surface area and can adsorb various pollutants which can remove pollutants from water and improve quality.

The properties and versatility of AgNPs have led them to be widely used in sensor systems. In fact, by changing the type of surface functionalization and by choosing a specific ligand, it is possible to make particles selective to a particular analyte, and by optimizing the degree of surface functionalization, their sensitivity can be improved [30]. Silver nanoparticles/graphene oxide nanocomposites (AG) Under sufficient conditions, could be used as an effective sensor to detect Hg(II) in the low range from 10 to 120 μg/L within a short time and with high selectivity[31].

However, there are concerns about the potential toxicity of silver nanoparticles to humans and aquatic organisms. Studies have shown that silver nanoparticles can accumulate in the environment and may have toxic effects on aquatic organisms. Therefore, it is important to carefully evaluate the risks and benefits of using nanoparticles in water treatment and to develop appropriate regulations for their use

4. Conclusion

In conclusion, the use of silver nanoparticles as disinfectants is a promising approach to fighting microbial infections. Their effectiveness against a wide range of microorganisms makes them a valuable tool for water treatment. Overall, the mode of action of AgNPs in water treatment is multifaceted and involves multiple mechanisms. The antibacterial activity of AgNPs is primarily due to the release of Ag^+ ions, physical interaction with bacterial cells, and generation of ROS. In addition, AgNPs can adsorb pollutants and improve water quality. These properties make AgNPs a promising material for water treatment applications. However, the use of AgNPs in water treatment also has some challenges. Firstly, the synthesis of AgNPs requires specialized equipment and expertise, which may limit their widespread use. Secondly, the long-term effects of AgNPs on human health and the environment are not fully understood. However, further research is needed to fully understand their potential toxicity and ensure their safe use.

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