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NANOSILVER AS ANTIMICROBIAL AGENT IN TREATMENT OF WATER/WASTE WATER

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ABSTRACT

Silver is an efficient antimicrobial agent used for removal of microorganisms from water/ waste water. Because of its smaller size, nano particles are effective in bacterial removal where used as filtering media. This review provides a comprehensive view on the mechanism of action silver nano particles (AgNPs) and their role in removing microorganisms. When AgNPs alone are used for treating water, it causes some problems such as agglomeration of particles, difficulty in separation from treated water, low hydraulic conductivity and excessive pressure drops. Thus for practical applications, Ag NPs are required to be coated onto some supports such as sand, polyurethane foam, zeolite, fiberglass etc. Coatings of AgNPs have potential impact in removing microorganisms from water as well as waste water.

Keywords: Anti Microbial Agent, Silver Nanoparticle

I. INTRODUCTION

Water is most important in shaping the land and regulating the climate. It is one of the most important compounds that profoundly influence life. The quality of water is usually described according to its physical, chemical and biological characteristics. Rapid industrialization and indiscriminate use of chemical fertilizers and pesticides in agriculture are causing heavy and varied pollution in aquatic environment leading to deterioration of water quality and depletion of aquatic biota. Due to use of contaminated water, human population suffers from water borne diseases [1].

More than 2000 million people would live under conditions of high water stress by the year 2050, according to the UNEP (United Nations Environment Programme), which warns water could prove to be a limiting factor for development in a number of regions in the world. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity of water, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage as per UN-water 2007.

Nanotechnology has been considered effective in solving water problems related to quality and quantity. Several commercial and noncommercial technological developments are employed on daily basis but nanotechnology has proved to be one of the advanced ways for water/waste water treatment. Developments in nanoscale research have made it possible to invent economically feasible and environmentally stable treatment technologies for

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effectively treating water/wastewater meeting the ever increasing water quality standards. It is suggested that nanotechnology can adequately address many of the water quality issues by using different types of nanoparticles (NPs) and/or nanofibers. Nanotechnology uses materials of sizes smaller than 100nm [2]. At this scale, materials possess novel and significantly changed physical, chemical, and biological properties mainly due to their structure, higher surface area-to-volume ratio. Nanoparticles (NPs) can penetrate deeper and thus can treat water/wastewater which is generally not possible by conventional technologies [3].

NPs can be broadly grouped in to two, namely, organic NPs that include carbon NPs and inorganic NPs that include magnetic NPs, noble metal NPs (such as gold and silver) and semi conductor NPs (such as titanium oxide and zinc oxide [4]. Metal NPs have a high specific surface area and high fraction of surface atoms. Ferromagnetic NPs are capable of removing organic/inorganic contaminants. Selective adsorption properties and increasingly large surface areas of NPs help in speedy treatment of water.

Metal NPs have a high specific surface area and a high fraction of surface atoms. Because of unique physicochemical characteristics of NPs, including catalytic activity, optical properties, and magnetic properties they are gaining interest of scientist for novel methods of synthesis. Silver is well known for possessing an inhibitory effect toward many bacterial strains and microorganisms commonly present in medical and industrial processes.

Silver is the most widely used material due to its low toxicity and microbial inactivation in water with well-reported antibacterial mechanism. AgNPs are derived from its salts like silver nitrate and silver chloride. The antibacterial effect is size dependent, smaller AgNPs (8 nm) are most effective, while larger particle size (11–23 nm) results in lower bactericidal activity [5]. Also, truncated triangular AgNPs exhibited better antibacterial effects than the spherical and rod-shaped nanoparticles indicating their shape dependency [6]. The mechanisms involved during the bactericidal effects of AgNPs include, for example, the formation of free radicals damaging the bacterial membranes, interactions with DNA, adhesion to cell surface altering the membrane properties, and enzyme damage In comparison with silver ions, the nanoparticles have longer lasting biocidal properties. They are less prone to complexation and precipitation into forms unavailable to bacteria. AgNPs are easier to incorporate into matrix materials such as paper, fibers, polymers and ceramics. Due to the nanometer-sized diameter of the nanoparticles, the surface area is much greater than the bulk metal, and is therefore more bioactive. Applications of AgNPs are currently of intense interest in nanotechnology.

There are many ways to synthesize AgNPs. These include physical, chemical, and biological methods. Many techniques of synthesizing AgNPs such as chemical reduction of silver ions in aqueous solutions with or without stabilizing agents, thermal decomposition in organic solvents, chemical reduction and photo reduction in reverse micelles, evaporation condensation using tube furnace, laser ablation and radiation chemical reduction are normally employed. The physical and chemical methods are numerous in number, and many of these methods are expensive or use of toxic substances which are major factors that make them unfavourable method for synthesis. The growing need to develop eco-friendly and economically feasible technologies for material synthesis led to the search for biological methods for synthesis. Three major sources of biosynthesizing of

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AgNPs are: bacteria, fungi, and plant extracts [7, 8].

The three major components involved in the preparation of nanoparticles using biological methods are the solvent medium for synthesis, the eco-friendly reducing agent, and a nontoxic stabilizing agent. Plants provide a better platform for nanoparticles synthesis as they are free from toxic chemicals as well as provide natural capping agents. Moreover, use of plant extracts also reduces the cost microorganism's isolation and culture media, enhancing the cost competitive feasibility over nanoparticles synthesis by microorganisms [8,9].

II. ANTIMICROBIAL ACTIVITY OF AGNPS

AgNPs seem to be alternative antibacterial agents to antibiotics and have the ability to overcome the bacterial resistance against antibiotics. Therefore, it is necessary to develop AgNPs as antibacterial agents. Among the several promising nanomaterials, AgNPs seem to be potential antibacterial agents due to their large surface-to-volume ratio and crystallographic surface structure.

The exact mechanism which AgNPs employ to cause antimicrobial effect is not clearly known and is a debated topic. There are however various theories on the action of AgNPs on microbes to cause microbicidal effect. The fig 1.1 shows various modes of action of AgNPs on bacteria. AgNPs have the ability to anchor to the bacterial cell wall and subsequently penetrate it, thereby causing structural changes in the cell membrane like the permeability of the cell membrane and death of the cell. There is formation of 'pits' on the cell surface, and there is accumulation of the nanoparticles on the cell surface .The formation of free radicals by the AgNPs may be considered to be another mechanism by which the cells die. There have been electron spin resonance spectroscopy studies that suggest the formation of free radicals by AgNPs when in contact with the bacteria, and these free radicals have the ability to damage the cell membrane and make it porous which can ultimately lead to cell death [10].

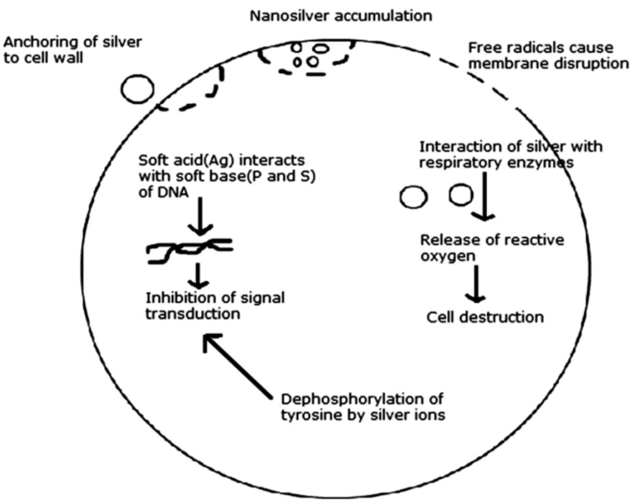

Fig 1.1 Various Modes of Action of Agnps on Bacteria (Prabhu Et Al., 2012)

It has also been proposed that there can be release of silver ions by the nanoparticles [11],and these ions can interact with the thiol groups of many vital enzymes and inactivate them [12]. The bacterial cells in contact with silver take in silver ions, which inhibit several functions in the cell and damage the cells. Then, there is the generation of reactive oxygen species, which are produced possibly through the inhibition of a respiratory enzyme by silver ions and attack the cell itself. Silver is a soft acid, and there is a natural tendency of an acid to react with a base, in this case, a soft acid to react with a soft base [13]. The cells are majorly made up of sulfur and phosphorus which are soft bases. The action of these nanoparticles on the cell can cause the reaction to take place and subsequently lead to cell death. Another fact is that the DNA has sulfur and phosphorus as its major components; the nanoparticles can act on these soft bases and destroy the DNA which would definitely lead to cell death . The interaction of the silver nanoparticles with the sulfur and phosphorus of the DNA can lead to problems in the DNA replication of the bacteria and thus terminate the microbes [8].

It has also been found that the nanoparticles can modulate the signal transduction in bacteria. It is a well established fact that phosphorylation of protein substrates in bacteria influences bacterial signal transduction. Dephosphorylation is noted only in the tyrosine residues of gram-negative bacteria. The phosphotyrosine profile of bacterial peptides is altered by the nanoparticles. It is found that the nanoparticles dephosphorylate the peptide substrates on tyrosine residues, which leads to signal transduction inhibition and thus the stoppage of growth. It is however necessary to understand that further research is required on the topic to thoroughly establish the claims [8,14].

III. EFFECT OF NANOSILVER COATING IN REMOVAL OF MICROORGANSMS

When silver nanoparticles are applied in flow through systems, it faces some problems such as agglomeration of particles, difficulty in separation from treated water, low hydraulic conductivity and excessive pressure drops. Thus for practical applications, AgNPs is required to be coated onto some supports such as sand, polyurethane foam, zeolite, fibreglass etc.

Embedded Ag nanoparticles have been reported as very effective against both Gram-positive and Gram-negative bacteria [15]. In a study, cellulose acetate fibers embedded with Ag nanoparticles formed by direct electrospinning method [16] were shown effective against both types of bacteria. Ag nanoparticles are also incorporated into different types of polymers for the production of antimicrobial nanofibers and nanocomposites [17,18]. Poly (ε-caprolactone-) based polyurethane nanofiber mats containing Ag nanoparticles were used as antimicrobial nanofilters [19]. Different types of nanofibers containing Ag nanoparticles were prepared for antimicrobial application and exhibited very good antimicrobial properties [20,21]. Water filters prepared by polyurethane foam coated with Ag nanofibers have shown good antibacterial properties against *Escherichia coli* (*E. coli*) [22].

There are other examples of low-cost potable microfilters prepared by incorporating Ag nanoparticles that can be used in remote areas in developing countries [23]. Ag nanoparticles also find their applications in water filtration membranes, for example, in polysulfone membranes [24], for biofouling reduction and have proved effective against variety of bacteria and viruses [25,26]. These Ag nanoparticles laden membranes had good antimicrobial activities against *E. coli*, *Pseudomonas*, and so forth [27].

Farhana & Meera [28] conduct study on nanosilver coated sand which was prepared using three different plant extract for reducing silver to nanoscale. Nanosilver coated sand synthesized using papaya fruit extract gave the highest percentage coating of silver. Nanosilver coated sand synthesized by plant extracts may be used as an efficient filter media in water/waste water treatment for removal of microorganisms. The microbial removal by nanosized particles coated on sand showed enhanced efficiency when compared to silver coated sand in treatment of roof harvested rain water.

Karnib et al [29] compared ability of the activated carbon, silver impregnated activated carbon, and silica sand to eliminate and destroy water borne *E. coli* BL21. They were tested under plate assay and shake flask technique. AgNPs showed the highest antibacterial effect against E. *coli* BL21 with inhibition zone diameter 18 mm. On using the shake flask technique it was shown that bacterial count started to reducing after one hour of incubation, while no bacterial growth is detected after 2,3 and 24 hours using the activated carbon. Bacterial growth is completely inhibited on using silver impregnated activated carbon at all the tested concentrations after one hour of incubation. Silver impregnated activated carbon and silica sand against waterborne pathogenic *E.coli* BL21 is obtained and compared. Plate assays and shake flask methods showed that silica sand had the lowest antibacterial activities compared to silver coated activated carbon.

Monyatsi et al [30] studied the effect of low-cost filter materials with AgNPs, coated on zeolite,sand,fiberglass , anion and cation resin substrates, in various concentrations (0.01mM, 0.03mM, 0.05mM and 0.1mM) of $AgNO_3$. In the first phase, the five substrates coated with various concentrations of $AgNO_3$ were tested against E. coli spiked in synthetic water to determine the best loading concentration that could remove pathogenic bacteria completely from test water. The results revealed that all filters were able to decrease the concentration of E. coli from synthetic water, with a higher removal efficiency achieved at 0.1 mM (21–100%) and a lower efficiency at 0.01 mM (7–50%) concentrations. The cation resin-silver nanoparticle filter was found to remove this pathogenic bacterium at the highest rate, namely 100%. In the second phase, only the best performing concentration of 0.1 mM was considered and tested against presumptive *E. coli, S. typhimurium, S. dysenteriae and V. cholerae* from groundwater. The results revealed the highest bacteria removal efficiency by the Ag/cation resin filter with complete (100%) removal of all targeted bacteria and the lowest by the Ag/zeolite filter with an 8% to 67% removal rate. This study therefore suggests that the filter system with Ag/cation resin substrate can be used as a potential alternative cost-effective filter for the disinfection of groundwater and production of safe drinking water.

Yoon et al [31] coated silver particles on to an activated carbon fibre (ACF) filter, using an electroless deposition method and their efficacy for bioaerosol removal was tested. The results showed that the silver-deposited ACF filters were effective for the removal of bioaerosols by inhibition of the survival of microorganisms, whereas pristine ACF filters were not. Two bacteria, *Bacillus subtilis* and *Escherichia coli*, were completely inhibited within 10 and 60 min, respectively, which eventually prevented secondary contamination of ACF filters by breeding of bacteria. Even though the electroless silver deposition did not influence the physical properties of the ACF filters such as the pressure drop and filtration efficiency, the adsorptive efficacy was decreased by silver deposition. Therefore, the silver content needs to be optimized according to the species and the concentrations of background bioaerosols in the intended area of application of the silver-deposited ACF filters.

VI. CONCLUSIONS

Silver has always been an excellent antimicrobial agent. The unique physical and chemical properties of silver nanoparticles are responsible for the increase in silver efficiency. Though there are many mechanisms attributed to the antimicrobial activity shown by silver nanoparticles, the actual and most reliable mechanism is not fully understood or cannot be generalized as the nanoparticles are found to act on different organisms in different ways. Coating of AgNPs on sand, polyurethane foam, zeolite, fibreglass, activated carbon, etc. enhance the removal of microorganisms.

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