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A Role of Nano-Science in Drinking Water Refining Systems

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ABSTRACT

Recently, nanotechnology is an emerging and fast-growing technology. Silver nano-particle (AgNP) play an important role in nano-science and nanotechnology, particularly in water refining system. Silver nano-particles account for more than 23% of all nano-products. The extensive application of the silver nano-particle results in their inevitable release into the environment. Silver nano-particles are known as excellent antimicrobial agents, and therefore they could be used as alternative disinfectant agents. In this paper, we introduce the background information on the environmental fate, toxicological effects, and application of AgNP and review the current knowledge on the physicochemical and antimicrobial properties of AgNP in different aqueous solutions, as well as their application in water-treatment systems.

Keywords: Nano-Science, Silver Nano-Particle, Water Refining System

I. INTRODUCTION

Nano-particles are defined as small particles sized between 1 to 100 nanometers in at least one dimension. Currently there are more than 1317 nanotechnology-based consumer products according to an analysis by Nanotechproject.com [1, 5]. Silver nano-particles (AgNPs) are increasingly used in various fields, including medical, food, health care, consumer, and industrial purposes, due to their unique physical and chemical properties. These include optical, electrical, and thermal, high electrical conductivity, and biological properties [1-4]. Due to their peculiar properties, they have been used for several applications, including as antibacterial agents, in industrial, household, and healthcare-related products, in consumer products, medical device coatings, optical sensors, and cosmetics, in the pharmaceutical industry, the food industry, in diagnostics, orthopedics, drug delivery, as anticancer agents, and have ultimately enhanced the tumor-killing effects of anticancer drugs [1]. Recently, AgNPs have been frequently used in many textiles, keyboards, wound dressings, and biomedical devices [2, 5, 6]. Nano sized metallic particles are unique and can considerably change physical, chemical, and biological properties due to their surface-to-volume ratio; therefore, these nano-particles have been exploited for various purposes [7, 8]. In order to fulfill the requirement of AgNPs, various methods have been adopted for synthesis. Generally, conventional physical and chemical methods seem to be very expensive and hazardous. Interestingly, biologically-prepared AgNPs show high yield, solubility, and high stability [1].

Nano-particles are defined as small particles sized between 1 to 100 nanometers in at least one dimension. Currently there are more than 1317 nanotechnology-based consumer products according to an analysis by Nanotechproject.com[5]. Compared to their counterparts in bulk states, manufactured nano-materials have the merits of better adjustable electronic properties, better tunable optical properties, and higher reactivity. Among all the nano-products, 313 products (23%) are impregnated with nano-sized silver. Silver nano-particles (AgNP) are used in a wide range of applications, including pharmaceuticals, cosmetics, medical devices, foodware, clothing and water purification among others uses, due to their antimicrobial properties [6].

II. METHODS

AgNP can be prepared by various methods including chemical reduction, electrochemical techniques, and photochemical reduction [7]. Among all the synthetic methods, chemical reduction is most commonly used. However, toxic compounds such as borohydride are usually involved. Studies have focused on "green" synthesis approaches to avoid using hazardous materials. The Tollens method is widely applied for AgNP synthesis. Environmentally benign monosaccharides and polysaccharides are used to reduce the $Ag(NH3)2^{+}$ complex formed by reacting $AgNO_3$ with ammonia to AgNP.

Previous studies have produced AgNP with sizes ranging from 50-200 nm and silver hydrosols ranging from 20-50 nm [8-10]. Panacek et al. [8] synthesized AgNP by reduction of the Ag(NH3)2 + complex with two monosaccharides, glucose and galactose, and two disaccharides, maltose and lactose, and found the average particle size ranged from 25 to 450 nm at various ammonia concentrations (0.005-0.2 M) and pH conditions (11.5-13.0) [8].

Aggregation during synthesis can hinder the production of AgNP with small and uniform sizes. For antimicrobial purposes, formation of aggregates can reduce the antimicrobial ability of AgNP [10-12]. Stabilizers are incorporated in the AgNP manufacturing process to ensure their stability in aqueous solutions. Absorption of the stabilizing molecules onto the nano-particle surface depends on the molecular weight, ionization, and charge density of the stabilizing molecules [6, 4, 13, 14]. Stabilizing layers can increase the electrostatic and steric repulsion between nano-particles and therefore enhance the stability of the nanosuspension [6, 15]. Commonly used stabilizing agents include different surfactants (such as sodium dodecyl sulfate (SDS) and Tween) and polymers including Polyvinylpyrrolidone (PVP) [16], Polyvinyl Achohol (PVA) [15], starch [14, 17], and various proteins [12].

III. RESULTS AND DISCUSSION

Recently, WHO/UNICEF estimated that 783 million people in the world do not have access to safe drinking water [18]. Boschi-Pinto et al. [19] reported 1.87 million childhood deaths are due to water-borne diseases [19]. Conventional water treatment and delivery approaches are considered unfeasible in these under-developed areas because they need high capital investments, a high cost of maintenance, a high quantity water source, and these require users to pay for the treated water [20]. People have to collect their own water outside their homes and then store the water in the household due to the lack of water supply, and contaminations could occur during the water collection, transport, and storage, which cause a high chance of water-borne disease infection [20]. A point-of-use (POU) ceramic water filter (CWF) provides an option to purify the water.

A ceramic water filter (CWF) is a simple device that can eliminate water-borne pathogens. Currently, CWFs are manufactured by pressing and firing a mixture of clay and a burnable organic material such as flour, rice husks, or sawdust before treatment with AgNP [21]. The filter is formed using a filter press, after which it is air-dried and fired in a kiln. This forms the ceramic material and burns off the sawdust, flour, or rice husk in the filters, making it porous and permeable to water. CWFs are reported as effective in removing more than 99% of protozoa and 90-99.99% of bacteria from drinking water [22]. However, a high removal of viruses is not achieved. AgNP and silver nitrate (AgNO3, Ag+) are added to filters at all CWF factories to achieve higher pathogen removal due to their antimicrobial properties [22]. The silver solutions are applied to CWF either by brushing or dipping [23]. It was reported that 83% of CWF factories apply AgNP and 17% use Ag+ [23]. The concentration of silver applied at CWF factories varies. Reported amounts of AgNP applied on CWFs ranges from 32 to 96 mg per CWF [23]. Current guidelines recommend 64 mg of AgNP per CWF [23].

Two mechanisms of microorganism disinfection by CWFs were suggested. (i) CWFs can remove microorganisms by size exclusion or adsorption; (ii) AgNP or Ag+ inside of CWFs can inactivate pathogens [23]. Figure 1-5 shows the bacteria trapped inside of CWFs coated with AgNP or Ag+ .

Although studies have addressed the pathogen reduction of silver-coated CWFs manufactured with different materials, other manufacturing conditions may affect the performance of CWFs. When applying silver on CWFs, a variety of water sources is used at factories to prepare silver solutions, from untreated surface water to treated water. Water characteristics at the filter user's home also vary with location. Previous studies have reported a reduction in antibacterial properties of AgNP with increased size of the nano-particle clusters due to aggregation in the presence of divalent ions such as Ca2+ and Mg2+ [11].

Numerous studies have investigated the pathogen removal performance of silverimpregnated CWFs. Table 1 summarizes these studies, including the types of silver and pathogens as well as the removal performances.

In addition, environmental waters usually contain organic compounds, such as humic acids (HA) [11]. These natural organic matter compounds can rapidly coat the nanoparticle surfaces, creating a physical barrier that prevents interaction between nanoparticles and bacteria. While previous studies have reported that different water chemistry conditions can have an impact on the disinfection performance of AgNP in the aqueous phase [11], these parameters have not been evaluated on CWFs either in the field or in laboratory tests.

Due to the silver application, desorption of silver from coated CWFs has been reported during the first flushes of water. Previous studies using a phosphate buffer as an influent solution reported a decrease in silver concentration in effluent from AgNP impregnated CWFs to below the United States Environmental Protection Agency (USEPA) maximum contaminant level (MCL) for silver in drinking water (0.1 mg/L or 100 ppb) within few flushes [29]. However, no comprehensive study has evaluated the desorption of either AgNP or Ag+ from CWFs using different clays and water chemistry conditions.

Table I. Summary of Pathogen Removal Performance of Silver Coated CWFS Manufactured With Different Clay Materials

PATHOGEN TYPES	**PATHOGEN REDUCTION PERFORMANCE**		**TYPES OF SILVER**	**TYPE OF CLAY**	**REF.**
	%	LRV			
E. coli		>2	AgNP	Nicaraguan	64
Cryptosporidium parvum		4.3			
MS2 bacteriophage		<1			
E. coli		2.9	AgNP	Nicaraguan	65
E. coli		>3	AgNP	Nicaraguan	66
E. coli		7	AgNP	Nicaraguan	54
Clostridium spores		3.3-4.9			
MS2 bacteriophage		<1			
E. coli		3	AgNP	Nicaraguan	67
E. coli	>97.8		AgNP	Guatemalan, Redart, Mexican	55
E. coli		4.5	AgNP	Nicaraguan	63
E. coli	99		Ag+	Cambodian	56
MS2 bacteriophage	90-99				
E. coli		4.56	AgNP	Guatemalan	68

IV.CONCLUSION

Silver application in CWFs has advantages in reducing pathogens. However, the price of silver has increased significantly in the past few years, from approximately $10 to $30 per ounce [30].
The increase in the price of silver is threatening the sustainability of CWFs. Therefore, alternative disinfectants are needed to ensure the antimicrobial efficacy of the CWF system. One promising disinfectant agent candidate is 3-(trihydroxysilyl) propyldimethyloctadecyl ammonium chloride (TPA), which is a quaternary amine functionalized silsesquioxane compound. Getman [31] compared the antimicrobial performance between TPA and silver and found that TPA can deactivate 99.99% of E. coli in a nylon-thin film, while silver does not exhibit any performance during a one hour antimicrobial test [31]. In addition to its high antimicrobial properties, TPA powder is less expensive (~ $222 per kg) than silver (~ $1024 per kg). TPA is currently applied as an antibacterial or anti-mold reagent. Its applications include integration into thermoplastics or thermoset; dissolution in water and other solvents for use in coating, as with caulk or adhesive formulations; and application as a surface treatment for disinfection purposes [31].

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