

## Dung dịch nano bạc, các phương pháp điều chế, những đặc tính và khả năng ứng dụng

Nguyễn Đức Hùng\*

*Viện Hóa học và Vật liệu, Viện Khoa học Công nghệ Quân sự, Việt Nam*

Ngày nhận bài: 28/09/2023; Ngày sửa bài: 23/10/2023;

Ngày nhận đăng: 08/11/2023; Ngày xuất bản: 28/02/2024

### TÓM TẮT

Sự phát triển của vật liệu qua các thời kỳ: đồ đá, đồng, sắt, cao phân tử và hiện nay là vật liệu nano. Với các kích thước cực nhỏ, diện tích bề mặt rất lớn và hiệu ứng lượng tử vật liệu nano mang lại nhiều đặc tính vượt trội và ứng dụng đặc biệt. Vật liệu nano bạc (AgNPs) vừa mở rộng và bổ sung những đặc tính mới của Ag nên phạm vi ứng dụng cũng phát triển hơn, đặc biệt trong lĩnh vực môi trường, y học và bảo vệ sức khỏe con người. AgNPs được điều chế từ kim loại “trên xuống” hoặc từ ion “dưới lên” bằng các phương pháp vật lý, hóa học, hóa lý, sinh học hoặc kết hợp hỗn hợp. Sản phẩm AgNPs là dung dịch thật keo có những đặc tính rất phụ thuộc vào các phương pháp điều chế, song những đặc tính cơ bản như cộng hưởng bề mặt plasmonic của hạt nano bạc bằng UV-Vis, hình dạng, kích thước và cấu trúc hạt bằng TEM, SEM, AFM, FTIR, XPS, XRD, phân bố cỡ hạt bằng Laser Scattering Particle Size Distribution Analyzer và Zeta Phoremeter Instrumentation. Nồng độ nano bạc được xác định bằng AAS, ICP-MS, ICP-OES. Tùy thuộc vào mục đích sử dụng vào lĩnh vực: xúc tác, quang điện, vi điện tử, môi trường, y dược, sức khỏe,..còn xác định thêm các phương pháp xác định các tính chất tương ứng. Do AgNPs có nhiều đặc tính đặc biệt nhất là lĩnh vực diệt nhiều vi khuẩn bảo vệ môi trường và sức khỏe con người nên chiến lược nghiên cứu phát triển AgNPs được đặc biệt chú ý tại nhiều quốc gia trên thế giới.

**Từ khóa:** AgNPs, các phương pháp điều chế, những đặc tính, khả năng ứng dụng.

\*Tác giả liên hệ chính.

Email: [nguyenduchung1946@gmail.com](mailto:nguyenduchung1946@gmail.com)

# Silver nano solution: manufacturing methods, characteristics and applicability

Nguyen Duc Hung\*

*Institute for Chemistry and Materials, Academy of Military Science and Technology, Vietnam*

*Received: 28/09/2023; Revised: 23/10/2023;*

*Accepted: 08/11/2023; Published: 28/02/2024*

## ABSTRACT

The development of human society is associated with the development of materials through the ages of stone, copper, iron, polymers and now nano materials. With extremely small sizes, very large surface areas and quantum effects of nanomaterials, nano materials offer many outstanding properties and opens up many special applications. Silver nanoparticles (AgNPs) have both the properties of metallic silver while expanding and adding new properties, so the application scope is also more developed, especially in the fields of environment, medicine and human health protection. Silver nano is prepared according to the principle of "top-down" from metal or "bottom-up" from ion by physical, chemical, physicochemical or biological techniques or a mixture of combinations. The obtained silver nano product is a true colloidal solution whose properties are very dependent on the preparation methods, but the basic properties are the nature of the plasmonic surface resonance of silver nanoparticles by UV-Vis, particle shape, size and structure by TEM, SEM, AFM, FTIR, XPS, XRD, nanoparticle and colloidal size distribution by Laser Scattering Particle Size Distribution Analyzer and Zeta Phoremeter Instrumentation. The concentration of nano silver is usually determined by methods such as AAS, ICP-MS, ICP-OES. Depending on the intended use in the fields of catalysis, photovoltaic, microelectronics, environment, medicine, health, etc., methods to determine the corresponding properties are also applied. AgNPs has many special characteristics, the most prominent of which is in the field of killing many bacteria and viruses to protect the environment and human health, so the AgNPs development research strategy is specially noticed in many countries in the worlds.

**Keywords:** AgNPs, methods, characteristics, applicability.

## 1. INTRODUCTION

Metallic silver was discovered thousands of years BC and has become a very precious metal used as currency in feudal society in many countries as well as jewelry and household items.<sup>1</sup> With properties as good conductor of electricity, heat, light sensitivity and antiseptic, silver has been used in the fields of electricity, electronics, film and medicine since very early. Since the

development of nanomaterials with effects on subatomic small size, large area and quantum,<sup>2,3</sup> silver nanoparticles (AgPNs) have also been focused on researching innovations such as:<sup>4,5</sup> electrical properties,<sup>6</sup> electronic,<sup>7</sup> catalytic,<sup>8</sup> and especially antibacterial.<sup>9-11</sup> Because AgNPs have many applications in science, technology and life, especially with very good antibacterial ability,<sup>12-14</sup> many research and manufacturing methods such as physics,<sup>15-17</sup> biology,<sup>18-20</sup>

---

\*Corresponding author:

Email: nguyenduchung1946@gmail.com

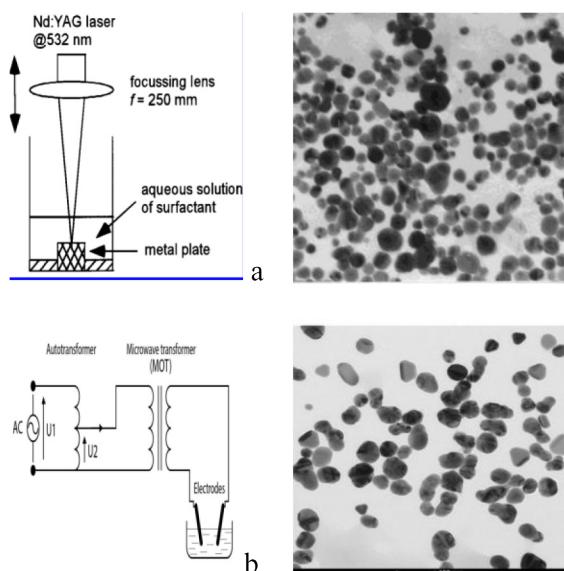
chemistry,<sup>21-23</sup> and electrochemistry<sup>24-27</sup> have focused their research, including new method to create high purity or local green raw materials are available and cheap.

## 2. MANUFACTURING METHODS

### 2.1. Physical methods

#### 2.1.1. The "top - down" approach

Fabrication of AgNPs by physical method follows the "top-down" principle with bulk metallic silver using a large amount of heat to separate the silver into vapor and then condense it like PVD,<sup>28,29</sup> or granular and then dispersed, such as laser cutting<sup>30,31</sup> or electric arc.<sup>32,33</sup> Figure 1 shows the principle of laser method (a)<sup>30</sup> and arc discharge (b)<sup>33</sup> along with corresponding TEM images of the obtained AgNPs particle size and shape and size.



**Figure 1.** Schematic diagram and TEM image of AgNPs, a) Laser method,<sup>30</sup> b) arc discharge method.<sup>33</sup>

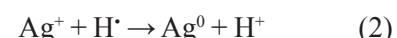
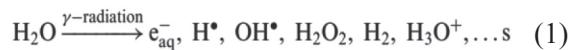
The AgNPs solution obtained by the above methods has a time-dependent light to dark yellow color and has a characteristic UV-Vis spectrum from 400 to 404 nm. Figure 1 shows that the shape of the nanoparticles is not uniform, so the particle size distribution spectrum is wide from 10 to 300 nm and the average is 46.8 to 48.9 nm. The zeta potential values from -20.4 to -22.31 mV show that AgNPs colloidal

solutions can be prepared by physical methods without the need for stable stabilizers. Although the production of AgNPs by the above physical methods does not use chemicals, it has high purity, but the equipment is complicated, uses a lot of energy, the concentration is not high and the quantity obtained is not large. Therefore, the cost is high and the field of use is limited.

#### 2.1.2. The "bottom - up" approach

Physical methods can implement the principle of preparing AgNPs from the "bottom-up" by beams: gamma,<sup>34-37</sup> electrons,<sup>38</sup> or microwave<sup>39</sup> activating components in solution to reduce Ag<sup>+</sup> of AgNO<sub>3</sub> salts into AgNPs.

According to the author group Bui Duy Du<sup>40</sup>, the energy of gamma rays can affect the components of the medium such as water to form strong reactive agents including strong reducing agents such as H- radical with potential value - 2, 3 V:



Although the obtained AgNPs have the best shape and small size, the fabrication process must use different stabilizers<sup>34-37,40,41</sup> and the maximum value of the UV-Vis spectrum ranges from 405.5 to 41.8 nm. With the advantage of using available equipment, the process of technology is not complicated and can prepare a large amount of AgNPs solution, so the cost will be more reasonable, but the resulting solution still has a large amount of NO<sub>3</sub><sup>-</sup> ions, as well as other stabilizers and by-products, the field of application is only suitable for environmental remediation.

## 2.2. Chemical methods

### 2.2.1. Reducing agents

The chemical method of preparing AgNPs solution is to follow the principle from the "bottom-up" to create nanoparticles from the Ag<sup>+</sup> ions of silver salts by reducing the

reduction process.<sup>42</sup> The commonly used silver salts are  $\text{AgNO}_3$  and the reducing agents that have been used very different such as glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ),<sup>43,44</sup> sacarose ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ),<sup>45</sup> hydrazine ( $\text{N}_2\text{H}_4$ ),<sup>46-48</sup> ethylene glycol ( $\text{C}_2\text{H}_6\text{O}_2$ ), ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), aniline ( $\text{C}_6\text{H}_5\text{NH}_2$ ),<sup>49</sup> sodium citrat ( $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ ),<sup>46,50-53</sup> hydrogen ( $\text{H}_2$ ),<sup>52</sup> sodium borhydrid ( $\text{NaBH}_4$ )<sup>53-57</sup> ...

**Table 1.** Reducing and reactions to create AgNPs.

Reducing agent	Reaction equation	Size, nm	Ref
$\text{C}_6\text{H}_{12}\text{O}_6$	$\text{C}_6\text{H}_{12}\text{O}_6 + 2\text{Ag}^+ + 2\text{OH}^- \rightarrow 2\text{Ag}^0 + \text{C}_6\text{H}_{12}\text{O}_7 + \text{H}_2\text{O}$ (4)	20.80 sphere	44
$\text{N}_2\text{H}_4$	$4\text{AgNO}_3 + \text{N}_2\text{H}_4 + 4\text{NaOH} \rightarrow 4\text{Ag}^0 + \text{N}_2 + 4\text{NaNO}_3 + 4\text{H}_2\text{O}$ (5)		48
$\text{N}_2\text{H}_4$	$4\text{AgNO}_3 + \text{N}_2\text{H}_4 \rightarrow 4\text{Ag}^0 + \text{N}_2 + 4\text{HNO}_3$ (6)	8-50 sphere	46
RCHO	$2\text{AgNO}_3 + \text{RCHO} + 2\text{NaO}^- \text{H} \rightarrow 2\text{Ag}^0 + \text{RCOOH} + 2\text{NaNO}_3 + \text{H}_2\text{O}$ (7)	10-250	49
$\text{C}_6\text{H}_5\text{NH}_2$	$\text{C}_6\text{H}_5\text{NH}_2 + \text{AgNO}_3 \rightarrow \text{Ag}^0 + \text{C}_6\text{H}_5\text{NH}_2\text{NO}_3$ (8)	10-30	49
$\text{C}_6\text{H}_5\text{O}_7\text{Na}_3$	$4\text{AgNO}_3 + \text{C}_6\text{H}_5\text{O}_7\text{Na}_3 + 2\text{H}_2\text{O} \rightarrow 4\text{Ag}^0 + \text{C}_6\text{H}_5\text{O}_7^- + 3\text{NaNO}_3 + \text{HNO}_3 + \text{O}_2$ (9)		50
$\text{NaBH}_4$	$\text{AgNO}_3 + \text{NaBH}_4 \rightarrow \text{Ag}^0 + 1/2\text{H}_2 + 1/2\text{B}_2\text{H}_6 + \text{NaNO}_3$ (10)	10-80	54-57
$\text{NaBH}_4$	$\text{AgNO}_3 + \text{NaBH}_4 + 3\text{H}_2\text{O} \rightarrow \text{Ag}^0 + 7/2\text{H}_2 + \text{B}(\text{OH})_3 + \text{NaNO}_3$ (11)	30-40	58

Table 1 presents the reaction equation to form AgNPs with a number of different reducers. To ensure the reduction process is completely done, the reducing agent usually has many times compared to silver salt. From the reactions in Table 1 it can be seen that in addition to the spherical silver nanoparticles after the reaction, there are ions of silver salt such as  $\text{NO}_3^-$ ,  $\text{Na}^+$ , the products of reducing agents and stabilizers are added. Removing these  $\text{Na}^+$  and  $\text{NO}_3^-$  ions to obtain pure AgNPs is very difficult and expensive and also changes the properties of AgNPs.

Therefore, products containing ions are only applied in areas that do not require high purity of AgNPs.

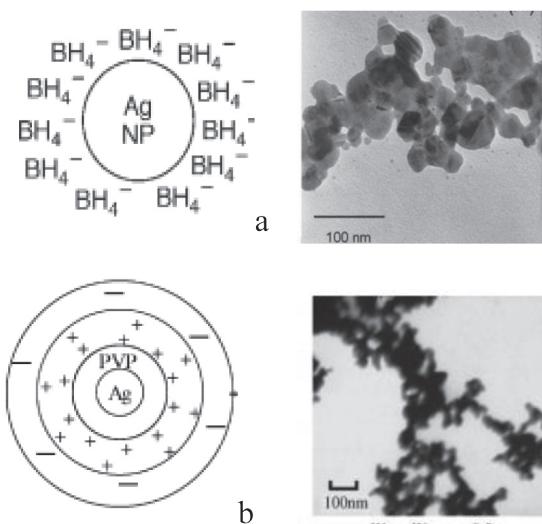
Table 1 also shows that nanoparticles are obtained as a wide area, so it is necessary to use stabilizers to control the size of nanoparticles as desired. From Table 1, the reducing reaction mechanism according to different authors<sup>54-58</sup> is also different. It means that the substances in AgNPs solution after the reaction will also vary, for example,  $\text{NaBH}_4$  reduction reaction (10) creating  $\text{B}_2\text{H}_6$ <sup>54-57</sup> gas will escape from the solution and if the reaction (11) quantity  $\text{H}_2$  gas from the solution is 3.5 times higher than (10).<sup>58</sup>

### 2.2.2. Stabilizers

The process of creating a silver nano colloidal solution with reducing agents that always exists in the system with ions and reducing agents, so silver colloids can be formed according to the equation:



and simulated as shown in Figure 2.<sup>44,54</sup>



**Figure 2.** AgNPs colloidal seeds and stamp images made up of  $\text{AgNO}_3$  chemical reduction with reducing agents: a)  $\text{NaBH}_4$ ,<sup>44</sup> b) R-HO with PVP.<sup>54</sup> [Ref.].

In order to control the size and shape of AgNPs in the colloidal solution, it is not

formed into a large particles, stabilizers are high molecular compounds or surfactants added to the chemical reaction.<sup>59-61</sup> Stabilizers often have functional groups, dissolve well in the reaction environment, good compatibility or high biological activity, non-toxic and biodegradable ability.<sup>62</sup> Table 2 is about presentation of some stabilizers often used for chemical manufacturing of AgNPs such as: chitosan,<sup>62-67</sup> PVA,<sup>68,69</sup> PVP,<sup>51,59,70</sup> ...

**Table 2.** Stabilizers often used in the process of chemical manufacturing of AgNPs.

Stabilizers	Chemical formula	M <sub>ever</sub> , g/mol	Ref.
Chitosan poly $\beta$ (1,4)D-glucosamine cation		3,800-20,000	66
PVP polyvinyl-pyrrolidone		40,000	59
PVA poly vinyl alcohol		85,000	
PAA polyacrylic acid		15,000	
PAH poly allylamine hydrochloride		15,000	
CMC carboxymethyl cellulose		90,000	
NaDDBS Surfactants (anion)		348	
SDS Surfactants (anion)		288	
TW80 Surfactants (neutral)		1,310	
CTAB Surfactants (cation)		365	

From Table 2, stabilizers can be found with electrical charge groups of straight or cyclic circuits, that can orient the adsorption on the AgNPs core to form a micell or reverse micell with the corresponding charge to combat flocculation of the colloidal system<sup>71,72</sup> so that the stabilizers with the appropriate nature and concentration will control the size and shape of the AgNPs colloid as well as the characteristics of AgNPs as desired.

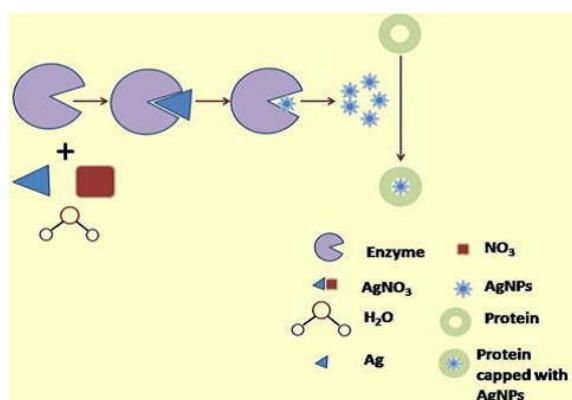
### 2.2.3. Silver nanocomposite

Fabrication of silver nanocomposite with chemical reducing processes will diversify AgNPs carried materials for applications in life. Composite materials carried AgPNs are usually studied as polymers PP, PET, Nylon, PC, ABS,<sup>73,74</sup> PU,<sup>75</sup> PE,<sup>76</sup> ceramic, pottery,<sup>77-79</sup> glass,<sup>80</sup> fabric, fiber,<sup>81-83</sup> paint.<sup>84-85</sup> Common manufacturing methods are dispersed AgNPs made by chemical methods in materials, but can also be made *in-situ* from AgNO<sub>3</sub> with reducing agents in the material during the processing ceramics, fabric or polymers.<sup>86-88</sup>

## 2.3. Biological method

### 2.3.1. Microorganism

The biology method uses bacterial microorganisms, yeast, mushrooms, molds as AgNO<sub>3</sub> silver-deducted agents into metal silver and AgNPs<sup>89-91,119</sup> microorganisms using silver salts as nutrients to survive and develop as described in Figure 3.



**Figure 3.** Microorganisms use Ag<sup>+</sup> as a nutrient and reduce it to AgNPs.<sup>91,119</sup>

From Figure 3 it can be seen that the protein can act as a stabilizer to control the size of AgNPs. There are many types of microorganisms studied and used to make AgNPs from  $\text{AgNO}_3$  which are presented in Table 3.

The results from Table 3 show that microorganisms can reduce  $\text{AgNO}_3$  salts to AgNPs with characteristic UV-Vis wavelengths from 380 to 460 nm and average particle sizes less than 100 nm. The special thing is that AgNPs products are stabilized with stable proteins for more than 6 months, so there is no need for stabilizers. However, the ions of  $\text{AgNO}_3$  salt are still present in the reaction product, so the purity of AgNPs is not enough for application in the field of medicine.

**Table 3.** Particle size, characteristic UV-Vis spectra and references of some typical microorganisms using AgNPs preparation.

Microorganism	Size/UV, nm	Ref.
<i>Enterobacteri</i>	52.5 / 420-430	92
<i>Rhodopseudomonas palustris</i>	5-20 / 420-460	93
<i>Rhodobacter Sphaeroides</i>	9.56 / 420	94
<i>vibrio alginolyticus</i>	75 / 420	95, 96
<i>Halococcus salifodinae BK6</i>	50.3 / 380-440	97
<i>Bacillus</i>	42-94 / 450	98
<i>Euplates focialii</i>	20-70 / 420	99
<i>Haloferax</i>	27.7 / 458	100
<i>Verticillium</i> (fungus)	25 / 420	101
<i>Aspergillus fumigatus</i>	5-25 / 420	102
<i>Penicilium</i>	5-25 / 430	103

### 2.3.2. Extraction solution – green chemistry

Humans develop in association with the plant environment and often use many types of plants for food or medicine, so using plants in the preparation of AgNPs is also a method with many advantages in terms of extremely rich raw materials, environmentally friendly and

low cost. Therefore, the method of preparing AgNPs by plant extracts has been studied all over the world such as USA,<sup>104</sup> China,<sup>105</sup> India,<sup>106</sup> Germany,<sup>107</sup> Africa<sup>108</sup> and Vietnam.<sup>109</sup> Water extracted from parts of plants such as leaves,<sup>110</sup> roots,<sup>111</sup> bark,<sup>112</sup> tubers,<sup>113</sup> flowers,<sup>114</sup> fruits<sup>115</sup> can all be used to prepare AgNPs. Table 4 presents extracts of some plants used to prepare AgNPs. Using plant water extract as  $\text{AgNO}_3$  reducing agent to prepare AgNPs does not need to use more stabilizers, but the product is still available with  $\text{NO}_3^-$  ions and reducing products, so it also limits the application field.

**Table 4.** Extracts of some plants used to prepare  $\text{AgNO}_3$ .

The plants	Science name	Part	Ref.
Geraniums	<i>pelargonium graveolens</i>	Flower	104
Cordyceps	<i>Cordyceps militaris</i>	Total	105
Mud	<i>Brillantaisia patula, Crossopteryx febrifuga and Senna siamea</i>	Tree and leaves	108
Soybean	<i>soymida febrifuga</i>	Total	110
Carrot	<i>D. carota</i>	Tubers	111
Dill	<i>Syzygium cumini</i>	Total	112
Turmeric	<i>Curcuma Longa</i>	Tubers	113
Hibiscus	<i>Hibiscus Rosa</i>	Flower	114
Papaya	<i>Papaya</i>	Fruit	115
Basil	<i>Ocimum sanctum</i>	Total	117
Ginger	<i>Zingiber officinale</i>	Total	123
Tea	<i>Camellia sinensis</i>	Leaf	125
Sinus	<i>Azadirachta indica</i>	Leaf	124

Sesame oil (castor oil)	<i>Jatropha curcas</i>	Total	126
Euphorbiaceae	<i>Acalypha Indica</i>	Total	135
Mint	<i>Mentha piperita</i>	Total	122
Chrysanthemum	<i>Stevia rebaudiana</i>	Total	134
Amaranthaceae	<i>Chenopodium album</i>	Total	120
Fabaceae	<i>Casia fistula</i>	Total	133
Terminalia	<i>Terminalia chebula</i>	Leaf	118
Cinnamon, Camphor	<i>Cinnamomum camphora zeylanicum</i>	Bark	121
Garlic	<i>Allium sativum</i>	Total	127
Curry patta	<i>Murraya koenigii</i>	Leaf	132
Lemon basil	<i>Coleus amboinicus</i>	Total	131
Alfalfa	<i>Medicago sativa</i>	Total	130
Oranges, Lemons	<i>Citrus sinensis</i>	Total	128
Lemongrass	<i>Lemon grass</i>	Total	119
Bình bát	<i>Coccinia grandis</i>	Leaf	129
Combretaceae	<i>Terminalia catappa</i>	Leaf	128
Aloe vera	<i>Aloe vera</i>	Leaf	116
Lime tree	<i>Robusta</i>	Leaf	109

From Table 4, it can be seen that plants from all continents of the world are food sources and spices such as oranges, lemons, papayas, sesame, basil to pharmaceuticals such as cinnamon, garlic, lemongrass, and cordyceps as well as wood-bearing trees such as neem tree, etc., which can be extracted using water

containing  $\text{AgNO}_3$  desalting agents into AgNPs. Common reducing agents in plant extracts are flavonoids, terpenoids, polyphenols, alkaloids, glucose which are compounds having carbonyl and hydroxyl groups or amine groups.<sup>136</sup>

## 2.4. Electrochemical method

### 2.4.1. Role of electrolyte

The electrochemical method in the field of Physical chemistry can perform a top-down process by oxidizing the metal silver anode in the electrolyte into  $\text{Ag}^+$  ions with electrode potential value  $+0.799 \text{ V}$ .<sup>137</sup>



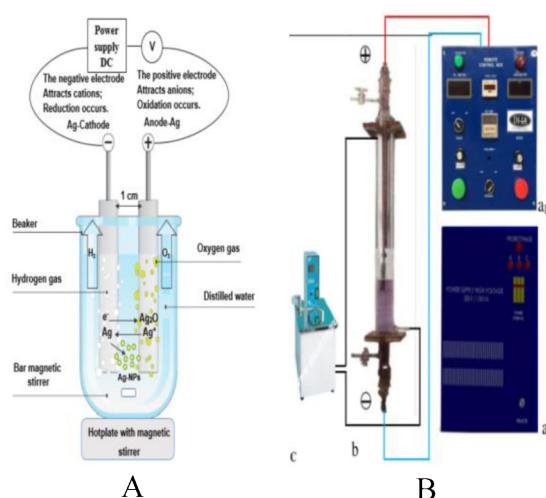
Simultaneously combined with the cathode reaction to reduce silver ions from the electrolyte to form silver nanoparticles, performing the bottom-up process:<sup>138-142</sup>



It is also possible to perform the preparation of AgNPs by simply reducing the reaction on the cathode (16) with  $\text{AgNO}_3$  salt dissolved in the electrolyte solution and an inert anode such as Pt.<sup>143,144</sup> To control the size of AgNPs obtained at the cathode, it is possible to use electrochemical parameters such as voltage, current density, conductivity as well as supporting measures such as pulses, ultrasound or will even produce strong gas release on the electrode at a higher voltage than conventional water electrolysis. With the usual electrochemical method, the electrolyte or anion  $\text{NO}_3^-$  of  $\text{AgNO}_3$  still exists in AgNPs products, so it also limits the application field.

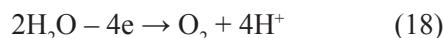
### 2.4.2. Role of applied voltage

Electrode reactions can occur in a non-electrolyte medium such as double distilled water with very low conductivity but the voltage must be sufficiently high<sup>138,139,141</sup> or very high.<sup>145-149</sup> There are two typical electrode arrangements in the electrochemical reactor when using high voltage (Figure 4).

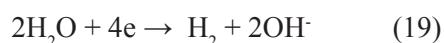


**Figure 4.** a) the cathode is parallel to the anode,<sup>140</sup> b) the bottom cathode is far from the upper anode<sup>146,148</sup>

With high DC voltage the potential drop across the electrodes will still be greater than the decomposition potential of water as well as the equilibrium electrode potential of Ag and the electrochemical oxidation on the anode to form  $\text{Ag}^+$  ions as the reaction (15) as well as water is electrochemically decomposed to form  $\text{O}_2$ :



At the same time on the cathode, the water will also be decomposed to form  $\text{H}_2$  gas that escapes strongly towards the anode as shown in Figure 4b:

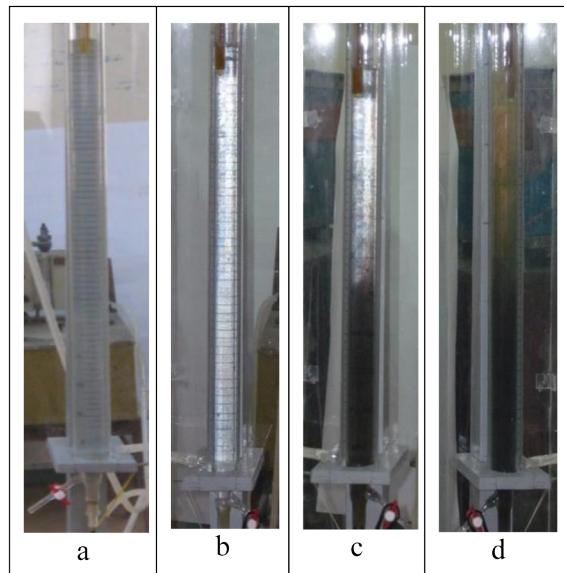


Due to the strong escaping gas covering the cathode surface, the amount of  $\text{Ag}^+$  ions generated from the anode moves slowly due to poor conductivity, so it is difficult to reach the cathode to carry out the reaction (16). Therefore, the process of reducing  $\text{Ag}^+$  to  $\text{Ag}^0$  and then to AgNPs according to (17) will be carried out with new  $\text{H}_2$  atoms generated from the cathode and dispersed into the solution:



Figure 5 shows the process of generating AgNPs by  $\text{H}_2$  generated from the cathode by electrochemical reaction from high voltage. Figure 5a shows that the color of distilled water

is transparent, but after 3 minutes of reaction,  $\text{H}_2$  gas escaping from the cathode turned white (b), and after 15 minutes of reaction, AgNPs formed turned dark color from the cathode side (c) and after 30 min the color of AgNPs occupied the entire reaction vessel (d).



**Figure 5.** AgNPs generation process by high voltage electrochemical reaction.

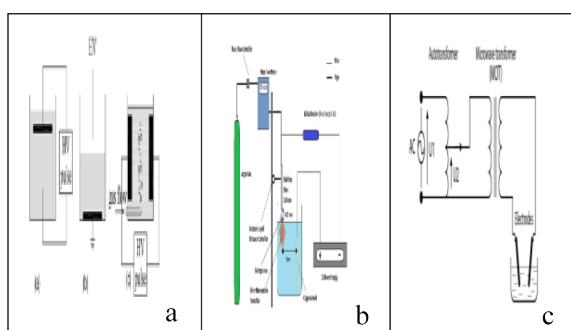
With the method of electrochemical manufacturing AgNPs by high voltage DC in distilled water with Ag electrode, the obtained product still has a spherical shape, size smaller than 100 nm with UV-Vis spectrum at about 420 nm and the ability to kill all kinds of bacteria very good. However, the zeta potential is opposite in sign to the chemical method and has a high value, so there is practically no need to use a stabilizer. The conductivity of colloidal solutions is very small because there are no ions of the reactants, so the high purity is suitable for applications where only AgNPs are required.

## 2.5. Plasma method

Plasma is the fourth state of matter, the ionized state is changed from a gaseous state when further energized.<sup>150</sup> Unlike high-temperature plasma which produces a fully ionized state with only electrons and ions, low-temperature plasma ionization process only partially contains not only electrons, ions but also atoms, neutral

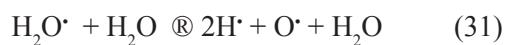
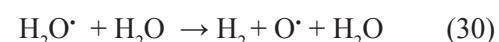
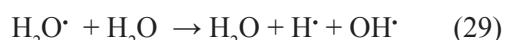
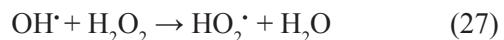
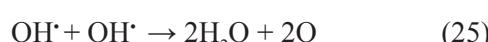
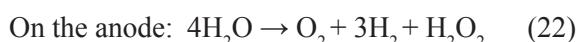
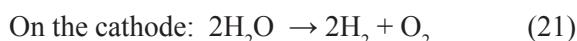
molecules and radicals and is being applied in many fields of science, technology and life.<sup>151</sup> The cold plasma state is also used for the preparation of AgNPs by the reduction of  $\text{AgNO}_3$  by free electrons or hydrogen atoms generated by plasma according to the reaction (16) or (20).<sup>152-154</sup> Figure 6 shows the plasma generation methods for the preparation of AgNPs.<sup>152,153,155</sup>

From Figure 6 it is shown that the gaseous medium can be used either by air on the surface (Figure 6A,b) or by blowing air between the two electrodes (Figure 6a and b) or by the ARC arc generating steam (Figure 6c).



**Figure 6.** Principle of plasma generation for the preparation of AgNPs.

The plasma generation process uses electrodes and electrochemical reactions to create a gaseous environment when the electrodes are arranged as shown in Figures 4b and Figures 5 or Figure 6a, so the plasma method can also be considered as an electrochemical method with high voltage. In the plasma state, the water will be decomposed on the electrodes to create a large amount of gas that does not obey Faraday's electrochemical theorem as well as ionization reactions to create atoms, molecules and radicals:<sup>152</sup>



UV rays in the presence of plasma also contribute to the radical reaction:



The reactants generated from the plasma medium can participate in the formation of AgNPs in addition to the reactions (16) and (20):

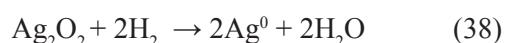
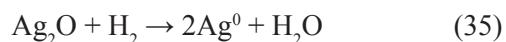
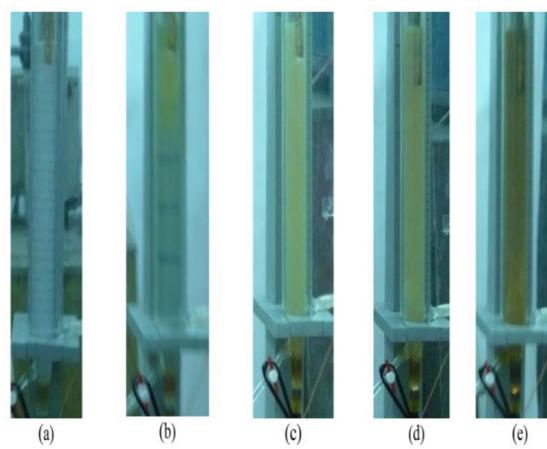


Figure 7 presents the process of generating AgNPs by high-voltage DC with the contribution of electrochemical plasma, showing that after the time of gas generation from the electrochemical reaction (Figure 7a), an anodic electrochemical plasma will appear after 15 minutes (Figure 7b) and the light yellow AgNPs color appearing from the anode towards the cathode gradually darkens over time of 23, 26, 35 min, respectively with Figures 7c, 7d and 7e.



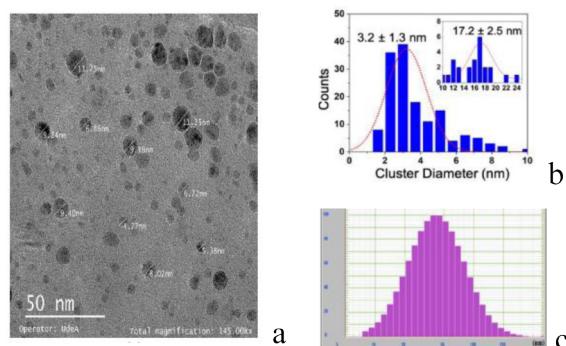
**Figure 7.** The process of generating AgNPs by high voltage DC with the contribution of electrochemical plasma.

The process of creating  $\text{Ag}_2\text{O}$  and  $\text{Ag}_2\text{O}_2$  intermediates besides  $\text{Ag}^0$  due to the presence of  $\text{O}_2$ ,  $\text{OH}^-$ ,  $\text{OH}^\cdot$ ,  $\text{H}_2\text{O}_2$  agents, etc. in the electrochemical plasma environment has created a yellow color before turning black.<sup>156</sup> By Ronghen, EDX and XPS spectra also demonstrated the presence of O in AgNPs accounting for 5.77, 9.6% and also increased the bactericidal efficiency of AgNPs.<sup>157-160</sup> Similar to the method of preparing AgNPs by High voltage DC, electrochemical plasma contribution will create the ability to increase the speed, product concentration as well as the ability to kill bacteria, although there is a small amount of  $\text{Ag}_2\text{O}$  or  $\text{Ag}_2\text{O}_2$ , but it does not affect the purity of the product.

### 3. CHARACTERISTICS OF NANOSILVER

#### 3.1. Silver nanoparticles

The characteristics of shape and size of AgNPs were determined by imaging methods by electron microscopy SEM, TEM, FE-TEM. Particle size distribution was determined by statistical particle counting software from SEM or by Laser Scattering Particle Size Distribution Analyzer. Figure 8 presents TEM images of AgNPs shape and size (a) as well as particle size distribution from TEM (b) and laser determination (c). Figure 8 shows that AgNPs prepared by different methods all have near-spherical shape but different sizes in the nanometer region with Gaussian distribution as determined by laser method.<sup>154,158,161</sup>

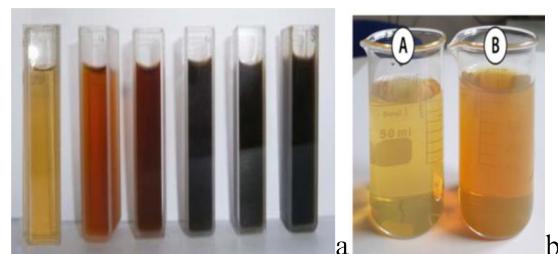


**Figure 8.** (a) TEM image of AgNPs, (b) particle size distribution counted from TEM image and (c) laser particle size distribution analysis.<sup>154,158,161</sup>

X-Ray,<sup>162</sup> XRD,<sup>153</sup> XPS<sup>142,152</sup> methods are also used to further investigate the properties of AgNPs particles in terms of phase, ratio of elements or ions:  $\text{Ag}/\text{Ag}^+/\text{O}$ , contributing to a better understanding of state of AgNPs in solution.

#### 3.2.1. Color

Figure 9 presents AgNPs products prepared by different methods such as: a) chemical,<sup>54</sup> or b) plasma.<sup>155</sup>

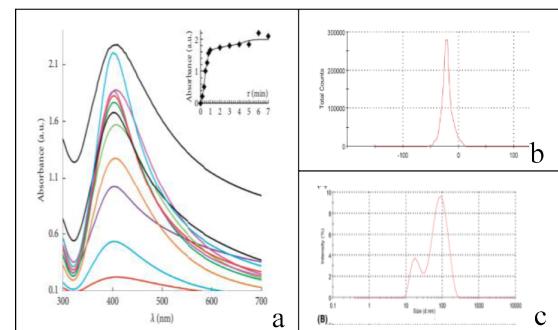


**Figure 9.** Color of AgNPs colloid a) chemically prepared,<sup>54</sup> b) by plasma at different times and concentrations.<sup>155</sup>

The AgNPs products obtained are all true solutions in the state of a transparent colloidal system with color from light yellow to brown or black depending on the concentration and preparation time, while the colorless solution will have no AgNPs.<sup>163</sup>

#### 3.2.2. UV-Vis and zeta potential

The AgNPs colloidal solution has the important properties of UV-Vis plasmon spectrum and zeta potential. Figure 10 shows the UV-Vis spectrum,<sup>164</sup> zeta potential and colloidal particle distribution.<sup>155</sup>



**Figure 10.** UV-Vis spectrum (a), zeta potential (b) and colloidal particle size distribution and (c) of AgNPs colloidal solution.

From Figure 10a, the UV-Vis spectrum can be found of the AgNPs colloidal solution that has a range of 400 nm and increases the height when the concentration or reaction time increases and the location is moved when the acacia grain nature is essentially affected. Figure 10b shows that the Zeta value is about -22.31 mV, proving that the surface of the AgNPs colloidal particles is positive and Figure 10c shows that the colloidal particles size is distributed from 20 to 90 nm. Therefore, Zeta is the diffusion layer, the surface of the colloidal particles should be dependent on the environment and charge of the AgNPs particles surface with values that change from yin and yang, but the absolute value is greater than 20 mV, the colloidal system will be durable over time. Table 5 presents the zeta value of AgNPs colloidal solutions with different stabilizers.<sup>60,66,139,159</sup>

**Table 5.** The zeta value of some stabilizers.

Stabilizer	Chemical formula	mW, g/mol	$\zeta$ , mV
NaDDBS	$C_{18}H_{29}SO_3Na$	348	5, -30
SDS	$C_{12}H_{25}SO_4Na$	288	-2, -20
TW80	$C_{64}H_{12}4O_{26}$	1310	4, -15
CTAB	$C_{19}H_{42}BrN$	365	20, -30
PVP	$(C_6H_9NO)n$	40000	0, -25
PAA	$(C_3H_3NaO_2)n$	14000	5, -25
PAH	$(C_3H_8ClN)n$	15000	5, 20
CMC	$(C_{28}H_{30}Na_8O_{27})$	90000	0, -10
Chitosan	$(C_6H_{11}NO_4)n$	20000	50, 70
PP SH <sup>165</sup>	<i>Entada spiralis</i>	Chiét	-80,7
PPDH <sup>139</sup>	DC 25 kV	Ag	-(27,39)
PPPL <sup>159</sup>	ARC discharge	Ag	-(40,70)

Table 5 shows that the value of zeta is very dependent on the nature of stabilization of chemical structure, weight, electronegativity,<sup>66,67</sup> as well as depending on the modulation method and composition of ions that exist in glue solution.

### 3.2.3. Conductivity and pH

Because  $Ag^0$  or AgNPs silver particles are dispersed in water environments, it is impossible to conduct electronic conduct as metal as well as ionic forms like electrolyte solution. However, while using  $AgNO_3$  in the methods as well as reducing the ionic amount of:  $NO_3^-$  as well as the reducing agent:  $Na^+$  or the products of the reducing agent will create the conductivity of the AgNPs solution. Moreover, AgNPs colloidal seeds adsorb ion and create charge.

**Table 6.** Electrical conductivity ( $\chi$ , mS/cm) and pH of AgNPs solution are prepared by chemical and electrochemical methods.

	$c$ , ppm	RO	100	200	300	500
Chem	$\chi$ , mS/cm	0,01	0,27	0,36	0,46	0,58
	pH	6,9	4,6	4,9	4,4	4,5
	$c$ , ppm	NC	109	185	285	411
Electr	$\chi$ , mS/cm	0,003	0,08	0,07	0,07	0,07
	pH	6,9	6,64	5,63	5,78	5,79

Table 6 also shows that with the methods using of  $AgNO_3$ , conductivity levels increases when the concentration increases, but the methods of electrochemical or plasma use the silver electrode, the conductivity is small and has almost no change, even when the synthesis time as well as when the concentration increases.<sup>166</sup>

### 3.2.4. Concentration of AgNPs

Determining the concentration of AgNPs is not as simple as determining the concentration of soluble substances because it is difficult to separate between silver nano and ionic. With AgNPs synthesis methods by using  $AgNO_3$  often think that the process of reaction completely and the AgNPs concentration is also considered as  $AgNO_3$  concentration. The AAS method transfers AgNPs to  $Ag^+$  so it cannot be determined by the nano form. With the methods of using Ag metal, it is possible to determine by soluble silver weight ( $c_{Dm}$ ) with the assumption that silver is

soluble for formation of AgNPs.<sup>167</sup> It can also determine the amount of AgNPs by adjectives The amount of electricity according to the law of Faraday ( $c_{Far.}$ ), but besides the dissolving process, there are other electrochemical processes, so the concentration of Faraday's law is usually larger than the amount of soluble metal ( $c_{Far.} > c_{Dm.}$ ).<sup>139</sup> The AAS method can also be used to determine the AgNPs concentration of the electrochemical and plasma modulation methods, but it cannot be separated from  $\text{Ag}^+$ . The UV-Vis spectroscopic method for the determination of AgNPs alone would be the most accurate, but standard curve construction is not feasible because standard solutions are difficult to obtain.

### 3.3. Antibacterial ability

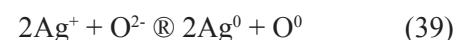
#### 3.3.1. Traditional

Since BC, silver's bactericidal properties have been used for prevention and treatment of diseases such as: acupuncture needles, containers for liquids and drinking water for the prevention and treatment of infections. Former feudal dynasties in many countries around the world used spoons, knives, bowls and plates in eating and drinking to kill pathogens to ensure life safety. Silver has also been used for a long time in dentistry, to treat neurological diseases, eye diseases, to treat wounds, and to disinfect drinking water systems. During the World Wars, colloidal silver was used to fight gastrointestinal diseases and infections. From the late 19th century to the present, colloidal silver has been used quite widely in the form of oral and injectable drugs to treat arthritis, bronchitis, respiratory, lung, influenza as well as gastrointestinal diseases, stomach ulcers or Disinfection of purulent-necrotic burn wounds, dermatosis, boils or even syphilis, mastitis, meningoencephalitis, vestibular,...<sup>168</sup>

#### 3.3.2. Outstanding antibacterial properties

Elemental silver has outstanding bactericidal ability because  $\text{Ag}^+$  ions exist in the form of salt.<sup>163</sup> In the form of AgNPs, with extremely large contact area, it is easy to provide  $\text{Ag}^+$ , so the bactericidal efficiency is improved many times. Although there is still no consensus, the

bactericidal mechanism of  $\text{Ag}^+$  aligned with 3 possibilities: (1) Destruction of the function of the cell wall; (2) Destruction of respiratory function due to inactivation of -SH group in  $\text{O}_2$  transporter; (3) Destruction of DNA function by dimerization of pyridine interferes with DNA replication of bacterial cells. In addition, atomic oxygen is produced from the reaction:



It also inhibits the growth of bacteria. Furthermore, the plasmons of AgNPs are susceptible to thermogenesis and destruction of bacteria. Because of many different ways to kill bacteria, the bactericidal ability of AgNPs cannot be greasy or resistant like current antibiotics.

#### 3.3.3. Antibacterials

Unlike antibiotics that are only suitable for bacteria, AgNPs can kill up to 650 types of bacteria, gram negative and positive as well as viruses and fungi, mold.<sup>168-170</sup> Recent studies have shown AgNPs have remarkable anti-inflammatory and antiviral potential, even against viruses such as HIV<sup>171,172</sup> or Sars corona,<sup>173,174</sup> Monkeypox,<sup>175</sup> Hepatitis B,<sup>176</sup> Syncytial,<sup>177</sup> Herpes,<sup>178</sup> Tacaribe,<sup>179</sup> West Nile, Hanta, Nipah, Hendra, Chikugunya, as well as viruses of avian origin and pig.<sup>173,180</sup>

#### 3.3.4. Toxicity

The toxicity of silver and silver ions has been of concern for a long time due to the phenomenon of blue skin when the amount of silver accumulates and has not been eliminated in time.<sup>180</sup> With its small size, it is dispersed in gaseous and liquid environments and solids when used, AgNPs also easily penetrate into the body and accumulate in cells through the respiratory tract,<sup>181</sup> esophagus or skin contact.<sup>182</sup> Therefore, the toxicity of AgNPs is also very noticeable.<sup>183,184</sup> Although AgNPs are not as toxic as ions, AgNPs still generate ions<sup>185</sup> from AgNPs and accumulate in organs such as lungs,<sup>186</sup> liver, and spleen<sup>187</sup> and cause harmful effects depending on the time and concentration of exposure<sup>188</sup> as well as the size, and the shape of AgNPs.<sup>189</sup>

## 4. APPLICATIONS

### 4.1. In chemistry

Silver metal as well as silver nano are applied due to its properties such as absorption and optical control, bactericidal, electrical and thermal conductivity, and especially as a catalyst for some reactions as well as as a sensor in analysis in chemistry.<sup>190</sup>

#### 4.1.1. Catalysis

The reduction of oxygen of epoxides to alkenes catalyzed by AgNPs can be 99% as efficient as using Au or AuNPs.<sup>191</sup> AgNPs are used as catalysts for the reduction reactions of nitro aromatic compound,<sup>192</sup> carbonyl as well as oxidation of alcohols, silanes, olefins, alkylation of amines and arenes as well as ring-opening or closing reactions and a variety of value reactions.<sup>193</sup> AgNPs are used as homogeneous or heterogeneous catalysts to synthesize many special chemical compounds with high efficiency such as:<sup>194</sup> pyrimido 96%, triazole 98%, pyrano 96%, isoxazole 93%, quinoline 88%, tetrazole 93%, benzopyranopyrimidine 95%, bivalent amine 92%, etc...

#### 4.1.2. Analysis

With advantages in size, shape and surface, silver nanomaterials also play an important role in determining and controlling electrical, optical, physical and especially chemical properties. With the GC electrode combined with AgNPs, it is possible to have excellent electrocatalytic activation as a sensor for determining  $H_2O_2$  in water with a concentration of 0.92  $\mu M$ .<sup>195</sup> With different techniques, it is possible to fabricate the mounted electrode. AgNPs for performing cyclic voltammetry CV, differential voltammetry DPV, linear sweep voltammetry LSV, square wave voltammetry SWV analyzes with up to the limit of ppb detection of various organic compounds.<sup>196</sup> Especially, it has advantages in detecting chemical contamination in the state of the environment, so the number of publications by 2022 has been increasing rapidly.<sup>197</sup>

### 4.2. In environmental treatment

The excellent bactericidal ability of AgNPs has been applied to environmental treatment mainly in three directions as surface disinfection, water disinfection and air sterilization.<sup>198</sup>

#### 4.2.1. Contact surface

Contact with material surfaces is the most frequent activity, so the antibacterial properties of AgNPs are also studied for applications in construction materials, fabrics or plastic tools. Interior paints with additive AgNPs 0.1, 0.5 ppm have good antibacterial effect.<sup>199</sup> Glass surface coated with AgNPs not only has bactericidal value but also has plasmon effect to increase absorption capacity. energy.<sup>200</sup> Plastic coated with AgNPs has many useful applications in medical transmission materials, in food packaging and preservation,<sup>201-203</sup> as well as export tropical fruits.<sup>204-206</sup> Fabric fibers surface coated with AgNPs with the amount of 180 mg/kg have a bactericidal effect of 99.28%, even after 30 washing cycles it is still 98.77%.<sup>207</sup>

#### 4.2.2. Water treatment

Water is necessary for the life of all things. Humans use water for all living activities as well as production, so they need clean water, but it is easy to pollute water sources with different wastes.<sup>208</sup> AgNPs with special chemical and biological properties should be noticed. It is intended for use in environmental treatment systems including water.<sup>209</sup> The European Union alone uses up to 20.5 tons of AgNPs to treat wastewater each year.<sup>210</sup> Effects of AgNPs in water treatment not only in the ability to kill bacteria but also in the chemical reaction ability<sup>211</sup> as well as sensor application to control water pollution.<sup>212</sup> In aquaculture, seafood AgNPs have also been used in water treatment to reduce pollution, infection as well as prevention of network diseases so as to have high economic efficiency.<sup>213-215</sup>

#### 4.2.3. Air handling

The excellent bactericidal effect of AgNPs has also been studied for application to air

purification. By depositing AgNPs into a porous quartz tube fitted with an air purifier with a capacity of 250 m<sup>3</sup>/h, it is possible to both process organic compounds up to 91.6% butanol, 80% acetone, and 70.1% diethyl ether and 43% benzene as well as 99% bacteria and fungi and installed for E Hanoi hospital.<sup>216</sup> The air conditioning system combined with AgNPs to improved heat transfer ability saved energy on average 36- 58%.<sup>217</sup> However, when using AgNPs to treat air pollution, great care must be taken to limit the dispersion of AgNPs into the air so as not to cause inflammation of the respiratory system.<sup>218</sup> Therefore, the concentration of AgNPs to spray in the air should also be kept to a low level and avoid long exposure times.<sup>219</sup>

### 4.3. In nanomedicine

AgNPs are widely used in many biomedical applications, known as nanomedicine including diagnostics, therapeutics, drug manufacturing, medical device coating, and personal healthcare. With increasing applications in medicine, a better understanding of the mechanisms is becoming necessary.<sup>220</sup>

#### 4.3.1. Disinfectant

Because the hospital environment needs to be clean, the special antibacterial ability of AgNPs is noticed as a disinfectant agent for the environment as well as tools. The MBC concentration of AgNPs for hospital bacterial strains such as *S. Aureus* or *P. Aeruginosa* in the operating room after 20 minutes is 100 µg/mL and after 24 hours it is 12.5 µg/mL.<sup>221</sup> Fluid pathways or medical instruments are also tested for emergency disinfection with AgNPs.<sup>201</sup> Even the air in hospital rooms can be treated with contamination by bacteria as well as organic substances with AgNPs.<sup>215</sup>

#### 4.3.2. Diagnose

Silver nanoparticles are used in imaging diagnosis and treatment of dental and oral cancers, acting as a carrier to disperse to targets along with chemotherapy agents and as radiation and phototherapy enhancers. It is valuable

for studying inflammation, tumors, immune responses, and the effects of stem cell therapy, in which contrast agents are conjugated or surface-modified and bioconjugated to particles. nano. Silver has an important role in imaging systems with plasmonic properties that should produce a clearer image.<sup>222,223</sup> Due to the reaction of AgPs with oxygen (ROS) of cancer cells, AgNPs have the effect of controlling and destroying DNA, contributing to the formation of nano cancer diagnosis and treatment in nano medicine.<sup>224,225</sup>

#### 4.3.3. Healing

The advantage of AgNPs is that they can kill many types of bacteria<sup>171-180</sup> and are not resistant to drugs like antibiotics,<sup>226</sup> so special attention is paid to exploiting them to treat diseases. Disinfecting all types of open wounds<sup>227</sup> especially in the treatment of burns<sup>228</sup> or teeth and mouth<sup>229</sup> with AgNPs not only heals the wound quickly but also leaves almost no scars after healing. With infectious diseases such as HIV, hepatitis, SARC, and chickenpox, injections with a concentration of 20 ppm of 10 nm AgNPs have achieved good curative effects.<sup>230</sup> Because cancer is currently an incurable disease, AgNPs have also been researched and applied and found that cancer cells have been inhibited by AgNPs from proliferating as well as angiogenesis due to the destruction of living and proliferation conditions.<sup>231</sup> Furthermore, AgNPs particles have the ability to absorb heat, so they can use energy from the laser source to kill cancer cells.<sup>232</sup>

## 5. CONCLUSION

Silver nano is prepared by chemical, physical, biological and physicochemical methods. Raw materials for the preparation process are AgNO<sub>3</sub> salt and reducing chemicals such as NaBH<sub>4</sub>, citrate salt, plant water as well as reducing microorganisms, or activating rays that create reducing properties of the solution such as  $\gamma$ . It is also possible to use Ag to disperse by laser or dissolve the anode into ions and then reduce it to form AgNPs. The appropriate purity for different practical applications of AgNPs products

depends on the method and materials used. Pure AgNPs solution is prepared by high-voltage electrochemical method or electrochemical plasma method because it only uses Ag and distilled water.

The basic characteristic of AgNPs is that the nanoparticle has a nearly spherical shape, the size is in the nanometer range and the UV-Vis spectrum is in the range of 420 nm with the height depending on the concentration and the pH value depending on the size. The zeta potential has an absolute value of  $\geq 20$  mV, which characterizes the stability of the silver nano colloid solution, then the negative or positive value depends on the method and the composition of ions in the solution. Pure AgNPs colloidal solution has a very small electrical conductivity, but the conductivity value will increase depending on the concentration of reducing agent ions or reaction products in the solution. A very important characteristic of AgNPs is the ability to kill microorganisms from positive and negative bacteria, viruses to fungus by destroying cell membranes, affecting -SH groups as well as destroying functions microbial DNA.

AgNPs are applied in chemical fields as catalysts and analytical sensors. In the environment, AgNPs are applied to treat bacterial infections as well as air and water pollution. In medicine, AgNPs is given special attention in research and application to treat environmental infections, medical tools and equipment; diagnose and heal many diseases, including dangerous diseases such as, burn, HIV, SARC and cancer.

## REFERENCES

1. C. R. Hammond. *Handbook of chemistry and physics (81<sup>st</sup> edition)*, CRC Press, Boca Raton, Florida, 2000.
2. K. E. Drexler. *Nanosystems: molecular machinery, manufacturing, and computation*, John Wiley & Sons, New York, 1992.
3. H. Goesmann, C. Feldmann. Nanoparticulate functional materials, *Angewandte Chemie – International Edition*, **2010**, *49*, 1362-1395.
4. S. Chernousova, M. Epple. Silver as antibacterial agent: ion, nanoparticle, and metal, *Angewandte Chemie - International Edition*, **2013**, *52*(6), 1636-1653.
5. B. C. Jiménez, M. E. Johnson, A. R. M. Bustos, K. E. Murphy, M. R. Winchester, J. R. V. Baudrit. Silver nanoparticles: technological advances, societal impacts, and metrological challenges, *Frontiers in Chemistry*, **2017**, *5*, 1-26.
6. N. Matsuhisa, M. Kaltenbrunner, T. Yokota, H. Jinno, K. Kuribara, T. Sekitani, T. Someya. Printable elastic conductors with a high conductivity for electronic textile applications, *Nature Communication*, **2015**, *6*, 7461.
7. D. Chen, X. Qiao, X. Qiu, J. Chen. Synthesis and electrical properties of uniform silver nanoparticles for electronic applications, *Journal of Material Science*, **2009**, *44*(4), 1076-1081.
8. X. Y. Dong, Z. W. Gao, K. F. Yang, W. Q. Zhang, L. W. Xu. Nanosilver as a new generation of silver catalysts in organic transformations for efficient synthesis of fine chemicals, *Catalysis Science & Technology*, **2015**, *5*, 2554-2574.
9. J. W. Alexander. History of the medical use of silver, *Surgical Infection (Larchmt)*, **2009**, *10*(3), 289-292.
10. S. Eckhardt, P. S. Brunetto, J. Gagnon, M. Priebe, B. Giese, K. M. Fromm. Nanobio silver: its interactions with peptides and bacteria, and its uses in medicine, *Chemical Reviews*, **2013**, *113*(7), 4708-4754.
11. S. B. N. Krishna, P. Govender, J. K. Adam. Biomedical applications and toxicity of nanosilver: a review, *Medical Technol SA*, **2015**, *29*(2), 13-29.
12. H. D. Beyene, A. A. Werkneh, H. K. Bezabh, T. G. Ambaye. Synthesis paradigm and applications of silver nanoparticles (AgNPs): a review, *Sustainable Materials and Technologies*, **2017**, *13*, 18-23.

13. J. V. Baudrit, S. M. Gamboa, E. R. Rojas, V. V. Martínez. Synthesis and characterization of silver nanoparticle and their application as an antibacterial agent, *International Journal of Biosensors & Bioelectronics*, **2019**, 5(5), 166-173.
14. L. Xu, Y. Y. Wang, J. Huang, C. Y. Chen, Z. X. Wang, H. Xie. Silver nanoparticles: synthesis, medical applications and biosafety, *Theranostics*, **2020**, 10(20), 8996-9031.
15. F. Mafuné, J. Y. Kohno, Y. Takeda, T. Kondow, H. Sawabe. Structure and stability of silver nanoparticles in aqueous solution produced by laser ablation, *The Journal of Physical Chemistry B*, **2000**, 104(35), 8333-8337.
16. M. Tsuji, M. Hashimoto, Y. Nishizawa, M. Kubokawa, T. Tsuji. Microwave-assisted synthesis of metallic nanostructures in solution, *Chemistry-A European Journal*, **2004**, 11(2), 440-452.
17. K. Shameli, M. B. Ahmad, W. M. Z. W. Yunus, N. A. Ibrahim, Y. Gharayebi, S. Sedaghat. Synthesis of silver/montmorillonite nanocomposites using  $\gamma$ -irradiation, *International Journal of Nanomedicine*, **2010**, 5, 1067-1077.
18. M. Behravan, A. H. Panahi, A. Naghizadeh, M. Ziae, R. Mahdavi, A. Mirzapour. Facile green synthesis of silver nanoparticles using *Berberis vulgaris* leaf and root aqueous extract and its antibacterial activity, *International Journal of Biological Macromolecules*, **2019**, 124, 148-154.
19. L. T. Hai, L. T. T. Uyen. Biosynthesis of silver nanoparticles from silver nitrate solution using aqueous extract of lemongrass leaves, *UED Journal of Social Sciences, Humanities & Education*, **2017**, 7(5), 5-9.
20. T. Sowmyya, G. V. Lakshmi. Green synthesis and characterization of silver nanoparticles using *Soyomida febrifuga* aqueous leaf extract, *World Journal of Pharmacy and Pharmaceutical Sciences*, **2015**, 5(1), 786-805.
21. K. Shameli, M. B. Ahmad, M. Zargar, W. M. Z. W. Yunus, N. A. Ibrahim, P. Shabanzadeh, M. G. Moghaddam. Synthesis and characterization of silver/montmorillonite chitosan bionanocomposites by chemical reduction method and their antibacterial activity, *International Journal of Nanomedicine*, **2011**, 6, 271-284.
22. N. H. Chau, L. A. Bang, N. Q. Buu, T. T. N. Dung, H. T. Ha, D. V. Quang. Some results in manufacture of nanosilver and investigation of its application for disinfection, *Advances in Natural Sciences*, **2008**, 9(2), 241-248.
23. M. A. Awad, A. Hendi, K. M. Ortashi, R. A. Alotaibi, M. S. Sharafeldin. Characterization of silver nanoparticles prepared by wet chemical method and their antibacterial and cytotoxicity activities, *Tropical Journal of Pharmaceutical Research*, **2016**, 15(4), 679-685.
24. G. R. Nasretdinova, R. R. Fazleeva, R. K. Mukhitova, I. R. Nizameev, M. K. Kadirov, A. Y. Ziganshina, V. V. Yanilkin. Electrochemical synthesis of silver nanoparticles in solution, *Electrochemistry Communications*, **2015**, 50, 69-72.
25. N. D. Hung, N. M. Thuy, M. V. Phuoc, N. Nhi. Preparation of nanosilver colloidal solution by anodic dissolution under high DC voltage, *Electrochemistry*, **2013**, 81(6), 454-459.
26. L. B. Naranjo, M. Vazquez, D. M. Benjumea, G. Cirob. Electrochemical synthesis of silver nanoparticles and their potential use as antimicrobial agent: a case study on *Escherichia coli*, *Portugaliae Electrochimica Acta*, **2012**, 30(2), 135-144.
27. N. D. Hung, V. N. Nam, L. V. Trung, T. T. N. Dung. Electrochemical preparation of nano silver by combining high DC voltage with anodic plasma, *Vietnam Journal of Science and Technology*, **2019**, 57(2), 186-198.
28. U. Backman. *Studies on nanoparticle synthesis via gas-to-particle conversion*, VTT Publications, Helsinki, Finland, 2005.
29. X. F. Zhang, Z. G. Liu, W. Shen, S. Gurunathan. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches, *International Journal of Molecular Science*, **2016**, 17(9), 1534.

30. F. Mafuné, J. Y. Kohno, Y. Takeda, T. Kondow. Formation and size control of silver nanoparticles by laser ablation in aqueous solution, *The Journal of Physical Chemistry B*, **2000**, 104, 9111-9117.
31. A. Pyatenko, K. Shimokawa, M. Yamaguchi, O. Nishimura, M. Suzuki. Synthesis of silver nanoparticles by laser ablation in pure water, *Applied Physical A: Materials Science and Processing*, **2004**, 79, 803-806.
32. D. C. Tien, C. Y. Liao, J. C. Huang, K. H. Tseng, J. K. Lung, T. T. Tsung, W. S. Kao, T. H. Tsai, T. W. Cheng, B. S. Yu, H. M. Lin, L. Stobinski. Novel technique for preparing a nano-silver water suspension by the arc-discharge method, *Reviews on Advanced Materials Science*, **2008**, 18(8), 752-758.
33. J. Jabłońska, K. Jankowski, M. Tomaszik, D. Cykalewicz, P. Uznański, S. Całuch, M. Szybowicz, J. Zakrzewska, P. Mazurek. Preparation of silver nanoparticles in a high voltage AC arc in water, *SN Applied Sciences*, **2021**, 3(244), 04177.
34. P. Chen, L. Song, Y. Liu, Y. E. Fang. Synthesis of silver nanoparticles by  $\gamma$ -ray irradiation in acetic water solution containing chitosan, *Radiation Physics and Chemistry*, **2007**, 76(7), 1165-1168.
35. D. V. Phu, B. D. Du, N. N. Duy, N. T. Anh, N. T. K. Lan, V. T. K. Lang, N. Q. Hien. The effect of pH and molecular weight of chitosan on silver nanoparticles synthesized by gamma-irradiation, *Vietnam Journal of Science and Technology*, **2009**, 47(6), 47-52.
36. D. Long, W. Guozhong, S. Chen. Preparation of oligochitosan stabilized silver nanoparticles by gamma irradiation, *Radiation Physics Chemistry*, **2007**, 76(7), 1126-1131.
37. H. S. Shin, H. J. Yang, S. B. Kim, M. S. Lee. Mechanism of growth of colloidal silver nanoparticles stabilized by polyvinyl pyrrolidone in  $\gamma$ -irradiated silver nitrate solution, *Journal of Colloid and Interface Science*, **2004**, 274(1), 89-94.
38. O. Dial, C. C. Cheng, A. Scherer. Fabrication of high-density nanostructures by electron beam lithography, *Journal of Vacuum Science & Technoloy B: Microelectronics and Nanometer Structures*, **1998**, 16(6), 3887-3890.
39. H. Jiang, K. S. Moon, Z. Zhang, S. Pothukuchi, C. P. Wong. Variable frequency microwave synthesis of silver nanoparticles, *Journal of Nanoparticle Research*, **2006**, 8(1), 117-124.
40. B. D. Du, D. V. Phu, N. N. Duy, N. T. K. Lan, V. T. K. Lang, N. V. K. Thanh, N. T. P. Phong, N. Q. Hien. Preparation of colloidal silver nanoparticles in poly(N-vinylpyrrolidone) by  $\gamma$ -irradiation, *Journal of Experimental Nanoscience*, **2008**, 3(3), 207-213.
41. N. T. Man, L. Hai, L. H. Tu, T. T. Hong, N. D. Hang, P. T. L. Ha, T. T. Thuy, T. T. Tam, N. T. H. Phong, L. X. Cuong. Preparation of silver nanoparticles by gamma irradiation method using chitosan as stabilizer, *Nuclear Science and Technology*, **2014**, 4(3), 43-46.
42. A. Salleh, R. Naomi, N. D. Utami, A. W. Mohammad, E. Mahmoudi, N. Mustafa, M. B. Fauzi. The potential of silver nanoparticles for antiviral and antibacterial applications: a mechanism of action, *Nanomaterials*, **2020**, 10, 1566-1586.
43. T. R. Sertbakan, E. K. A. Shakarchi, S. S. Mala. The preparation of nano silver by chemical reduction method, *Journal of Modern Physics*, **2022**, 13, 81-88.
44. H. Wang, X. Qiao, J. Chen, S. Ding. Preparation of nanoparticles by chemical reduction method, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **2005**, 256(2-3), 111-115.
45. N. T. Huong, N. V. Hung. Preparation of silver nano colloidal solution by reducing sucrose, *Journal of Military Science and Technology Research*, **2011**, 10(15), 86-91.
46. M. G. Guzmán, J. Dille, S. Godet. Synthesis of silver nanoparticles by chemical reduction method and their antibacterial activity, *International Journal of Chemical and Biomolecular Engineering*, **2009**, 2(3), 104-111.

47. V. V. Tatarchuk, A. P. Sergievskaya, T. M. Korda, I. A. Druzhinina, V. I. Zaikovsky. Kinetic factors in the synthesis of silver nanoparticles by reduction of  $\text{Ag}^+$  with hydrazine in reverse micelles of triton N-42, *Chemistry of Materials*, **2013**, 25(18), 3570-3579.
48. N. Q. Hien, N. T. A. Trinh, D. V. Phu, N. N. Duy, L. A. Quoc. Synthesis of silver nanoparticles doped in the zeolite framework by chemical reduction method, *Journal of Science and Technology*, **2015**, 53(3), 348-354.
49. S. M. Landage, A. I. Wasif, P. Dhuppe. Synthesis of nanosilver using chemical reduction method, *International Journal of Advanced Research in Engineering and Applied Sciences*, **2014**, 3(5), 14-22.
50. G. Suriati, M. Mariatti, A. Azizan. Synthesis of silver nanoparticles by chemical reduction method: effect of reducing agent and surfactant concentration, *International Journal of Automotive and Mechanical Engineering*, **2014**, 10(1), 1920-1927.
51. A. Shenava. Synthesis of silver nanoparticles by chemical reduction method and their antifungal activity, *International Research Journal of Pharmacy*, **2013**, 4(10), 111-113.
52. G. Krishna, S. C. Maringanti. Synthesis of silver nanoparticles by chemical and biological methods and their antimicrobial properties, *Journal of Experimental Nanoscience*, **2016**, 11(9), 714-721.
53. C. Q. Quiroz, N. Acevedo, J. Z. Giraldo, L. E. Botero, J. Quintero, D. Z. Triviño, J. Saldarriaga, V. Z. Pérez. Optimization of silver nanoparticle synthesis by chemical reduction and evaluation of its antimicrobial and toxic activity, *Biomaterials Research*, **2019**, 23(27), 1-15.
54. S. D. Solomon, M. Bahadory, A. V. Jeyarajasingam, S. A. Rutkowsky, C. Boritz. Synthesis and study of silver nanoparticles, *Journal of Chemical Education*, **2007**, 84(2), 322-325.
55. K. Mavani, M. Shah. Synthesis of silver nanoparticles by using sodium borohydride as a reducing agent, *International Journal of Engineering Research & Technology*, **2013**, 2(3), 1-5.
56. B. Zeytuncua, M. H. Morsali. Fabrication and characterization of antibacterial polyurethane acrylate-based materials, *Materials Research*, **2015**, 18(4), 867-872.
57. V. X. Hoa, D. T. T. Tra, P. T. T. Ha, D. K. Trinh, N. X. Huong, D. V. Son. Synthesis and study of silver nanoparticles for antibacterial activity against escherichia coli and staphylococcus aureus, *Advances in Natural Sciences: Nanoscience and Nanotechnology*, **2018**, 9(2), 025019.
58. K. C. Song, S. M. Lee, T. S. Park, B. S. Lee. Preparation of colloidal silver nanoparticles by chemical reduction method, *Korean Journal of Chemical Engineering*, **2009**, 26(1), 153-155.
59. F. Fischer, S. Bauer. Polyvinylpyrrolidon, ein tausendsassa in der chemie, *Chemie in Unserer Zeit*, **2009**, 43(6), 376-383.
60. E. Bae, H. J. Park, J. Park, J. Yoon, Y. Kim, K. Choi, J. Yi. Effect of chemical stabilizers in silver nanoparticle suspension on nanotoxicity, *Bulletin of the Korean Chemical Society*, **2011**, 32(2), 613-619.
61. D. Amir, R. R. Nasaruddin, N. S. Engliman, S. Sulaiman, M. S. Mastuli. Effect of stabilizers in the synthesis of silver nanoparticles and methylene blue oxidation, *IOP Conference Series: Materials Science and Engineering*, **2021**, 1192, 012031.
62. K. Shamel, M. B. Ahmad, M. Zargar, W. M. Z. W. Yunus, N. A. Ibrahim, P. Shabanzadeh, M. G. Moghaddam. Synthesis and characterization of silver/montmorillonite/chitosan bionanocomposites by chemical reduction method and their antibacterial activity, *International Journal of Nanomedicine*, **2011**, 6, 271-284.
63. M. A. Hettiarachchi, P. A. S. R. Wickramarachchi. Synthesis of chitosan stabilized silver nanoparticles using gamma ray irradiation and characterization, *Journal of Science of the University of Kelaniya*, **2012**, 6, 65-75.

64. J. V. Baudrit, R. A. Meza, F. S. Jiménez. Synthesis of silver nanoparticles using chitosan as a coating agent by sonochemical method, *Avances en Química*, **2014**, 9(3), 125-129.

65. R. Kalaivani, M. Maruthupandy, T. Muneeswaran, A. H. Beevi, M. Anand, C. M. Ramakritinan, A. K. Kumaraguru. Synthesis of chitosan mediated silver nanoparticles (AgNPs) for potential antimicrobial application, *Frontiers in Laboratory Medicine*, **2018**, 2(1), 30-35.

66. L. O. Cintea, C. Scomoroscenco, S. N. Voicu, C. L. Nistor, S. G. Nitu, B. Trica, M. L. Jecu, C. Petcu. Chitosan-stabilized Ag nanoparticles with superior biocompatibility and their synergistic antibacterial effect in mixtures with essential oils, *Nanomaterials*, **2018**, 8(10), 826-832.

67. L. Q. Luan, N. H. P. Uyen, P. H. Giang. Study on the antifungal effect of silver nano particlechitosan prepared by irradiation method on phytophthora capsica causing the blight disease on pepper plant, *Academia Journal of Biology*, **2014**, 36(1), 152-157.

68. M. J. Schnepf, M. Mayer, C. Kuttner, M. Tebbe, D. Wolf, M. Dulle, T. Altantzis, P. Formanek, S. Forster, S. Bals, T. A. F. Konig, A. Fery. Nanorattles with tailored electric field enhancement, *Nanoscale*, **2017**, 9(27), 9376-9385.

69. H. Kaczmarek, M. Metzler, K. W. Drzymalska. Effect of stabilizer type on the physicochemical properties of poly(acrylic acid)/silver nanocomposites for biomedical applications, *Polymer Bulletin*, **2016**, 73(10), 2927-2945.

70. J. J. Richards, A. D. Scherbarth, N. J. Wagner, P. D. Butler. Mixed ionic/electronic conducting surface layers adsorbed on colloidal silica for flow battery applications, *ACS Applied Materials & Interfaces*, **2016**, 8(36), 24089-24096.

71. K. Shiomori, T. Honbu, Y. Kawano, R. Kuboi, I. Komatsawa. Formation and structure control of reverse micelles by the addition of alkyl amines and their applications for extraction processes of proteins, *Studies in Surface Science and Catalysis*, **2001**, 132, 141-144.

72. B. S. Gangadharappa, M. Dammalli, S. Rajashekharappa, K. Murthy, G. B. Siddaiah. Reverse micelles as a bioseparation tool for enzymes, *Journal of Proteins and Proteomics*, **2017**, 8(2), 105-120.

73. L. J. Hua, C. G. Bac. Method for the preparation of silvernanoparticles-polymer composite, Patent Cooperation Treaty (PCT), World Intellectual Property Organization (WIPO), WO2005085339A1, 2005.

74. H. N. T. Luan, H. C. Cuong, H. T. C. Nhan, L. Q. Vinh, L. V. Hieu. Synthesis and study on mechanical properties of the polypropylene/TiO<sub>2</sub>-nano Ag composite for antibacterial application, *Science & Technology Development*, **2015**, 18(T1), 70-80.

75. H. A. Son, V. T. Phong, T. A. Tuan. Study and preparation of antiseptic filter film based on polyurethane/nanosilver composite for water treatment, *Journal of Analytical Sciences*, **2007**, 12(4), 3-8.

76. J. Deng, Q. M. Ding, W. Li, J. H. Wang, D. M. Liu, X. X. Zeng, X. Y. Liu, L. Ma, Y. Deng, W. Su, B. Ye. Preparation of nano-silver-containing polyethylene composite film and ag ion migration into food-simulants, *Journal of Nanoscience and Nanotechnology*, **2020**, 20(3), 1613-1621.

77. L. Yaohui, H. Liu, Z. Wang, S. Liu, L. Hao, Y. Sang, D. Liu, J. Wang, R. I. Boughton. Silver nanoparticle-decorated porous ceramic composite for water treatment, *Journal of Membrane Science*, **2009**, 331(1-2), 50-56.

78. M. Kumar, G. Pugazhenthi, D. Vasanth. Synthesis of zirconia-ceramic composite membrane employing a low-cost precursor and evaluation its performance for separation of microbially produced silver nanoparticles, *Journal of Environmental Chemical Engineering*, **2022**, 10(3), 107569.

79. N. D. Hung, N. T. T. Ha, T. T. N. Dung. Manufacturing of porous nanosilver-covered ceramic for waste water treatment in Thi Nai lagoon - Binh Dinh province, *Quy Nhon University Journal of Science*, **2016**, 10(4), 139-145.

80. N. D. Hung, N. T. Linh, T. T. N. Dung. Study on fabrication of antibacterial surface with nano silver for glass, ceramic, *Hanoi National University Journal of Science*, **2016**, 32(4), 53-57.
81. R. M. E. Shishtawy, A. M. Asiri, N. A. M. Abdelwahed, M. M. A. Otaibi. In situ production of silver nanoparticle on cotton fabric and its antimicrobial evaluation, *Cellulose*, **2011**, 18(1), 75-82.
82. S. Erdogan. Textile finishing with chitosan and silver nanoparticles against *Escherichia coli* ATCC 8739, *Trakya University Journal of Natural Sciences*, **2020**, 21(1), 21-32.
83. Y. N. Gao, Y. Wang, T. N. Yue, Y. X. Weng, M. Wang. Multifunctional cotton non-woven fabrics coated with silver nanoparticles and polymers for antibacterials, superhydrophobic and high performance microwave shielding, *Journal of Colloid and Interface Science*, **2021**, 582, 112-123.
84. J. Weber, L. Henssler, L. Zeman, C. Pfeifer, V. Alt, M. Nerlich, M. Huber, T. Herbst, M. Koller, W. S. Brachert, M. Kerschbaum, T. Holzmann. Nanosilver/DCOIT-containing surface coating effectively and constantly reduces microbial load in emergency room surfaces, *Journal of Hospital Infection*, **2023**, 135, 90-97.
85. H. Zhang, J. Cui, J. Zhu, Y. Shao, H. Zhang. Fabrication of nano-silver–silver ion composite antibacterial agents for green powder coatings, *Coatings*, **2023**, 13(3), 575.
86. T. T. N. Dung, N. H. Chau. Manufacturing silver nano - porous ceramic membrane for disinfection of drinking water by in-situ reduction method, *Vietnam Journal of Science and Technology*, **2015**, 53(6), 715-722.
87. M. S. Khalilabad, M. E. Yazdanshenas, A. Etemadifar. Fabricating multifunctional silver nanoparticles-coated cotton fabric, *Arabian Journal of Chemistry*, **2013**, 10, S2355-S2362.
88. K. M. F. Hasan, P. G. Horváth, Z. Kóczán, M. Bak, T. Alpár. Colorful and facile in situ nanosilver coating on sisal/cotton interwoven fabrics mediated from European larch heartwood, *Scientific Reports*, **2021**, 11(1), 22397.
89. D. Mandal, M. E. Bolander, D. Mukhopadhyay, G. Sarkar, P. Mukherjee. The use of microorganisms for the formation of metal nanoparticles and their application, *Applied Microbiology Biotechnology*, **2006**, 69(5), 485-492.
90. A. B. Moghaddam, F. Namvar, M. Moniri, P. M. Tahir, S. Azizi, R. Mohamad. Nanoparticles biosynthesized by fungi and yeast: a review of their preparation, properties, and medical applications, *Molecules*, **2015**, 20(9), 16540-16565.
91. N. T. Khan, M. J. Khan. Mycofabricated silver nanoparticles: an overview of biological organisms responsible for its synthesis, *Biochemistry & Molecular Biology Journal*, **2017**, 3(1), 1-5.
92. A. R. Shahverdi, S. Minaean, H. R. Shahverdi, H. Jamalifar, A. A. Nohi. Rapid synthesis of silver nanoparticles using culture supernatants of *Enterobacteria*: a novel biological approach, *Process Biochemistry*, **2007**, 42(5), 919-923.
93. C. C. Jing, B. H. Juan. Biosynthesis of silver nanoparticles using the phototrophic bacteria *rhodopseudomonas palustris* and its antimicrobial activity against *escherichia coli* and *staphylococcus aureus*, *Microbiology China*, **2010**, 37(12), 1798-1804.
94. H. J. Bai, B. S. Yang, C. J. Chai, G. E. Yang, W. L. Jia, Z. B. Yi. Green synthesis of silver nanoparticles using *rhodobacter sphaeroides*, *World Journal of Microbiology Biotechnology*, **2011**, 27(11), 2723-2728.
95. S. Rajeshkumar, C. Malarkodi, K. Paulkumar, M. Vanaja, G. Gnanajobitha, G. Annadurai. Intracellular and extracellular biosynthesis of silver nanoparticles by using marine bacteria *vibrio alginolyticus*, *Nanoscience and Nanotechnology: An International Journal*, **2013**, 3(1), 21-25.
96. S. Rajeshkumar, C. Malarkodi, V. Sivakumar, K. Paulkumar, M. Vanaja. Biosynthesis of silver nanoparticles by using marine bacteria *vibrio alginolyticus*, *International Research Journal of Pharmaceutical and Biosciences*, **2014**, 1(1), 19-23.

97. P. Srivastava1, J. M. Braganca, S. R. Ramanan, M. Kowshik. Green synthesis of silver nanoparticles by haloarchaeon halococcus salifodinae BK6, *Advanced Materials Research*, **2014**, 938, 236-241.

98. V. L. Das, R. Thomas, R. T. Varghese, E. V. Soniya, J. Mathew, E. K. Radhakrishnan. Extracellular synthesis of silver nanoparticles by the *Bacillus* strain CS 11 isolated from industrialized area, *3 Biotech*, **2014**, 4, 121-126.

99. M. S. John, J. A. Nagoth, K. P. Ramasamy, A. Mancini, G. Giuli, A. Natalello, P. Ballarini, C. Miceli, S. Pucciarelli. Synthesis of bioactive silver nanoparticles by a *pseudomonas* strain associated with the antarctic psychrophilic protozoon *euplotes focialii*, *Marine Drugs*, **2020**, 18(1), 38.

100. H. M. Tag, A. A. Saddiq, M. Alkinani, N. Hagagy. Biosynthesis of silver nanoparticles using *haloferax* sp. nrs1: image analysis, characterization, in vitro thrombolysis and cytotoxicity, *AMB Express*, **2021**, 11, 75.

101. P. Mukherjee, A. Ahmad, D. Mandal, S. Senapati, S. R. Sainkar. Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis, *Nano Letters*, **2001**, 1(10), 515-519.

102. K. C. Bhainsa, S. F. D. Souza. Extracellular biosynthesis of silver nanoparticles using the fungus *aspergillus fumigatus*, *Colloids and Surfaces B: Biointerfaces*, **2006**, 47(2), 160-164.

103. K. Kathiresan, S. Manivannan, M. A. Nabeel, B. Dhivya. Studies on silver nanoparticles synthesized by a marine fungus *penicillium fellutanum* isolated from coastal mangrove sediment, *Colloids and Surface B: Biointerfaces*, **2009**, 71(1), 133-137.

104. M. Pandian, R. Marimuthu, G. Natesan, R. E. Rajagopa, J. S. Justin, A. J. A. H. Mohideen. Development of biogenic silver nano particle from *pelargonium graveolens* leaf extract and their antibacterial activity, *American Journal of Nano Research and Applications*, **2013**, 1(2), 57-64.

105. L. Wang, C. C. Liu, Y. Y. Wang, H. Xu, H. Su, X. Cheng. Antibacterial activities of the novel silver nanoparticles biosynthesized using *cordyceps militaris* extract, *Current Applied Physics*, **2016**, 16(9), 969-973.

106. M. Zargar, A. A. Hamid, F. A. Bakar, M. N. Shamsudin, K. Shameli, F. Jahanshiri, F. Farahani. Green synthesis and antibacterial effect of silver nanoparticles using *vitex negundo* L., *Molecules*, **2011**, 16(8), 6667-6676.

107. M. Kowshik, S. Ashtaputre, S. Kharrazi, W. Vogel, J. Urban, S. K. Kulkarni, K. M. Paknikar. Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3, *Nanotechnology*, **2003**, 14(1), 95-100.

108. E. K. Kambate, C. I. Nkanga, B. P. I. Mutonkole, A. M. Bapolisi, D. O. Tassa, J. M. I. Liesse, R. W. M. Krause, P. B. Memvaga. Green synthesis of antimicrobial silver nanoparticles using aqueous leaf extracts from three Congolese plant species (*Brillantaisia patula*, *Crossopteryx febrifuga* and *Senna siamea*), *Heliyon*, **2020**, 6(8), 4493.

109. L. T. K. Anh, L. D. Vuong, V. V. Q. Bao, N. T. P. Nga, N. H. Thinh, N. T. Q. Anh, P. T. T. Hien. Synthesis of silver-nanoparticles with aqueous extract of robusta plant leaves as reducing agent, *Hue University Journal of Science: Natural Science*, **2022**, 131(1A), 119-126.

110. T. Sowmyya, G. V. Lakshmi. Green synthesis and characterization of antimicrobial and catalytic silver nanoparticles using *soymida febrifuga* aqueous leaf extract, *World Journal Pharmacy and Pharmaceutical Science*, **2016**, 5(1), 786-805.

111. M. Umadevi, S. Shalini, M. R. Bindhu. Synthesis of silver nanoparticle using *D. carota* extract, *Advances in Natural Science: Nanoscience and Nanotechnology*, **2012**, 3(2), 025008.

112. R. Prasad, V. S. Swamy. Antibacterial activity of silver nanoparticles synthesized by bark extract of *syzygium cumini*, *Journal of Nanoparticles*, **2013**, 2013, 431218.

113. K. Shameli, M. B. Ahmad, A. Zamanian, P. Sangpour, P. Shabanzadeh, Y. Abdollahi,

M. Zargar. Green biosynthesis of silver nanoparticles using Curcuma longa tuber powder, *International Journal of Nanomedicine*, **2012**, 7, 5603-5610.

114. A. Reveendran, S. Varghese, K. Viswanathan. Green synthesis of silver nano particle using hibiscus rosa sinensis, *IOSR Journal of Applied Physics*, **2016**, 8(3), 35-38.

115. D. Jain, H. K. Daima, S. Kachhwaha, S. L. Kothar. Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluation of their anti microbial activities, *Digest Journal of Nanomaterials and Biostructures*, **2009**, 4(3), 557-563.

116. Y. Zhang, X. Cheng, Y. Zhang, X. Xue, Y. Fu. Biosynthesis of silver nanoparticles at room temperature using aqueous aloe leaf extract and antibacterial properties, *Colloids Surfaces A: Physicochemical and Engineering Aspects*, **2013**, 423(2), 63-68.

117. L. T. Hai, N. T. L. Anh. Biosynthesis of silver nanoparticles from  $\text{AgNO}_3$  solution using aqueous extract of ocimum basilicum L. leaf as the reducing agent, *GSC Advanced Research and Reviews*, **2023**, 14(1), 151-158.

118. L. T. Hai. Biosynthesis, characterization and photocatalytic activity of copper/copper oxide nanoparticles produced using aqueous extract of lemongrass leaf, *Composite Materials*, **2019**, 3(1), 30-35.

119. C. Ankit, M. M. Sharma, A. Singh. Green nanoparticle synthesis and their applications, *International Journal of Pharmacognosy*, **2015**, 2(3), 110-115.

120. A. D. Dwivedi, K. Gopal. Biosynthesis of silver and gold nanoparticles using chenopodium album leaf extract, *Colloids Surfaces A: Physicochemical and Engineering Aspects*, **2010**, 369(1-3), 27-33.

121. J. Huang, Q. Li, D. Sun, Y. Lu, Y. Su, X. Yang, H. Wang, Y. Wang, W. Shao, N. He. Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnamomum camphora* leaf, *Nanotechnology*, **2007**, 18(10), 105104.

122. M. S. Shirazi, M. M. Farimani, A. Foroumadi, K. Ghanemi, M. Benaglia, P. Makvandi. Bioengineered synthesis of phytochemical-adorned green silver oxide ( $\text{Ag}_2\text{O}$ ) nanoparticles via mentha pulegium and ficus carica extracts with high antioxidant, antibacterial, and antifungal activities, *Scientific Reports*, **2022**, 12, 21509.

123. M. Mohammadi, S. A. Shahisaraee, A. Tavajjohi, N. Pournoori, S. Muhammadnejad, S. R. Mohammadi, R. Poursalehi, H. H. Delavari. Green synthesis of silver nanoparticles using zingiber officinale and thymus vulgaris extracts: characterisation, cell cytotoxicity, and its antifungal activity against candida albicans in comparison to fluconazole, *IET Nanobiotechnology*, **2019**, 13(2), 114-119.

124. S. A. Kumari, A. K. Patlolla, P. Madhusudhanachary. Biosynthesis of silver nanoparticles using azadirachta indica and their antioxidant and anticancer effects in cell lines, *Micromachines: Basel*, **2022**, 13(9), 1416.

125. Y. Y. Loo, B. W. Chieng, M. Nishibuchi, S. Radu. Synthesis of silver nanoparticles by using tea leaf extract from camellia sinensis, *International Journal of Nanomedicine*, **2012**, 7, 4263-4267.

126. H. Bar, D. K. Bhui, G. P. Sahoo, P. Sarkar, S. P. De, A. Misra. Green synthesis of silver nanoparticles using latex of jatropha curcas, *Colloids and Surfaces A Physicochemical and Engineering Aspects*, **2009**, 339(1-3), 134-139.

127. M. Abbas, T. Hussain, J. Iqbal, A. U. Rehman, M. A. Zaman, K. Jilani, N. Masood, S. H. A. Mijalli, M. Iqbal, A. Nazir. Synthesis of silver nanoparticle from allium sativum as an eco-benign agent for biological applications, *Polish Journal Environmental Studies*, **2022**, 31(1), 533-538.

128. J. Yadav, P. Chauhan. Green synthesis of silver nanoparticles using *citrus x sinensis* (orange) fruit extract and assessment of their catalytic reduction, *Materialstoday: Proceedings*, **2022**, 62(10), 6177-6181.

129. Y. H. Momim, V. C. Yeligar. Synthesis of coccina grandis (L.) voigt extract's silver nanoparticles and it's *in vitro* antidiabetic activity, *Journal of Applied Pharmaceutical Science*, **2021**, 11(8), 110815.

130. K. Song, D. Zhao, H. Sun, J. Gao, S. Li, T. Hu, X. He. Green nanopriming: responses of alfalfa (*Medicago sativa* L.) seedlings to alfalfa extracts capped and light-induced silver nanoparticles, *BMC Plant Biology*, **2022**, 22(323), 1-16.

131. S. Vadivel, S. Suja. Green synthesis of silver nanoparticles using coleus amboinicus lour, antioxidant activity and invitro cytotoxicity against Ehrlich's Ascite carcinoma, *Journal of Pharmacy Research*, **2012**, 5(2), 1268-1272.

132. N. K. Sajeshkumar, P. J. Vazhacharickal, J. J. Mathew, A. Sebastin. Synthesis of silver nano particles from cury leaf (*muraya koenigii*) extract and its antibacterial activity, *CIBTech Journal of Pharmaceutical Sciences*, **2015**, 4(2), 15-25.

133. Y. K. Mohanta, S. K. Panda, K. Biswas, A. Tamang, J. Bandyopadhyay, D. De, D. Mohanta, A. K. Bastia. Biogenic synthesis of silver nanoparticles from cassia fistula (Linn.): in vitro assessment of their antioxidant, antimicrobial and cytotoxic activities, *IET Nanobiotechnology*, **2016**, 10(6), 438-444.

134. M. Timotina, A. Aghajanyan, R. Schubert, K. Trchounian, L. Gabrielyan. Biosynthesis of silver nanoparticles using extracts of stevia rebaudiana and evaluation of antibacterial activity, *World Journal of Microbiology Biotechnology*, **2022**, 38(11), 196.

135. C. Krishnaraj, E. G. Jagan, S. Rajasekar, P. Selvakumar, P. T. Kalaichelvan, N. Mohan. Synthesis of silver nanoparticles using *Acalypha indica* leaf extracts and its antibacterial activity against water borne pathogens, *Colloids and Surfaces B: Biointerfaces*, **2010**, 76(1), 50-56.

136. M. Rai, C. Posten. *Green biosynthesis of nanoparticles: mechanisms and applications*, CABIDigital Library, Wallingford, Oxfordshire, 2013.

137. N. D. Hung. Electrochemical technology and metal protection, *Journal of Science and Technology*, **2012**, 50(6), 767-79.

138. R. A. Khaydarov, R. Khaydarov, O. Gapurova, Y. Estrin, T. Schepers. Electrochemical method for the synthesis of silver nanoparticles, *Journal of Nanoparticle Research*, **2009**, 11(5), 1193-1200.

139. N. D. Hung, M. V. Phuoc, N. M. Thuy. Manufacturing of nano silver solution using electrochemical technology, *Vietnam Journal of Chemistry*, **2012**, 50(2), 261-263.

140. M. J. Haider, M. S. Mahdi. Synthesis of silver nanoparticles by electrochemical method, *Engineering and Technology Journal*, **2015**, 33B(7), 1361-1373.

141. H. A. P. Sierra, G. P. Rodríguez, G. C. Bedoya. Silver colloidal nanoparticles by electrochemistry: temporal evaluation and surface plasmon resonance, *Journal of Physics: Conference Series*, **2021**, 2046, 012064.

142. C. Gasbarri, M. Ronci, A. Aceto, R. Vasani, G. Iezzi, T. Florio, F. Barbieri, G. Angelini, L. Scotti. Structure and properties of electrochemically synthesized silver nanoparticles in aqueous solution by high-resolution techniques, *Molecules*, **2021**, 26(17), 5155.

143. N. D. Hung, N. C. Phuc. Bactericidal activity of electrochemically precipitated nanosilver and Ag/Al<sub>2</sub>O<sub>3</sub> nanocomposites, *Vietnam Journal of Chemistry*, **2010**, 48(4), 409-412.

144. M. V. Roldán, N. Pellegrini, O. D. Sanctis. Electrochemical method for Ag-PEG nanoparticles synthesis, *Journal of Nanoparticles*, **2013**, 2013, 524150.

145. T. Q. Tuan, P. V. Hao, L. M. Quynh, N. H. Luong, N. H. Hai. Preparation and properties of silver nanoparticles by heat-combined electrochemical method, *VNU Journal of Science: Mathematics-Physics*, **2015**, 31(2), 36-44.

146. N. D. Hung, T. V. Cong, H. N. Trang. Synthesis of bimetallic Cu-Ag nanoparticles prepared by DC high voltage electrochemical method, *Vietnam Journal of Chemistry*, **2019**, 57(5), 609-614.

147. M. V. Phuoc, N. M. Thuy, N. D. Hung. Energy balance in the process of creating silver nanoparticles by high voltage electrochemical

technology, *Vietnam Journal of Chemistry*, **2014**, 52(6B), 183-186.

148. N. M. Thuy, N. D. Hung, M. V. Phuoc, N. N. Tru. Characterization of particles size distribution for nano silver solution prepared by high DC voltage electrochemical technique, *Vietnam Journal of Chemistry*, **2014**, 52(5), 543-547.

149. N. M. Thuy, N. D. Hung, N. T. N. Tinh, N. N. Tru. Silver nano solution produced by electrochemical method high voltage: bactericidal ability and application in medicine-pharmaceutical, *Vietnam Journal of Chemistry*, **2012**, 50(5A), 134-138.

150. D. A. F. Kamenetski. *Plasma, the fourth state of matter*, Plenum Press, New York, 1972.

151. P. K. Chu, X. Lu. *Low temperature plasma technology, methods and application*, CRC Press-Taylor&Francis Group, Boca Raton, 2013.

152. M. Er. *Synthesis of silver nanoparticles using a plasma-liquid process*, PhD thesis, Université Sorbonne Paris, 2020.

153. U. Shuaib, T. Hussain, R. Ahmad, M. Zakaullah, F. E. Mubarik, S. T. Muntaha, S. Ashraf. Plasma-liquid synthesis of silver nanoparticles and their antibacterial and antifungal applications, *Materials Research Express*, **2020**, 7(3), 035015.

154. V. S. Santosh, K. Kondeti, U. Gangal, S. Yatom, P. J. Bruggeman. Ag<sup>+</sup> reduction and silver nanoparticle synthesis at the plasma-liquid interface by an RF driven atmospheric pressure plasma jet: mechanisms and the effect of surfactant, *Journal of Vacuum Science & Technology A*, **2017**, 35(6), 1-12.

155. J. Jabłońska, K. Jankowski, M. Tomaszik, D. Cykalewicz, P. Uznański, S. Cahuch, M. Szybowicz, J. Zakrzewska, P. Mazurek. Preparation of silver nanoparticles in a high voltage AC arc in water, *SN Applied Sciences*, **2021**, 3(2), 244.

156. N. D. Hung, V. V. Nam, L. V. Trung, T. T. N. Dung. Electrochemical preparation of nanosilver by combining high DC voltage with anodic plasma, *Vietnam Journal of Science and Technology*, **2019**, 57(2), 186-198.

157. X. Wang, H. F. Wu, Q. Kuang, R. B. Huang, Z. X. Xie, L. S. Zheng. Shape-dependent antibacterial activities of Ag<sub>2</sub>O polyhedral particles, *Langmuir*, **2010**, 26(4), 2774-2778.

158. N. M. Thuy. Research on electrochemical anodic dissolution at positive electrode (anode) for manufacturing of silver nanoparticles using high voltage, PhD thesis, Military Academy of Science and Technology, Hanoi, 2010.

159. C. Gasbarri, M. Ronci, A. Aceto, R. Vasani, G. Iezzi, T. Florio, F. Barbieri, G. Angelini, L. Scotti. Structure and properties of electrochemically synthesized silver nanoparticles in aqueous solution by high-resolution techniques, *Molecules*, **2021**, 26, 5155.

160. A. Y. Vasilkov, R. I. Dovnar, S. M. Smotryn, N. N. Iaskevich, A. V. Naumkin. Plasmon resonance of silver nanoparticles as a method of increasing their antibacterial action, *Antibiotics*, **2018**, 7(3), 1-18.

161. Y. Niu, E. Omurzak, R. Cai, D. Syrgakbekkkyzy, Z. Z. kubanalievich, A. Satyvaldiev, R. E. Palmer. Eco-friendly synthesis of silver nanoparticles using pulsed plasma in liquid of surfactants, *Surfaces*, **2022**, 5(1), 202-208.

162. M. Skiba, A. Pivovarov, A. Makarova, V. Vorobyova. Plasma-chemical synthesis of silver nanoparticles in the presence of citrate, *Chemistry Journal of Moldova*, **2018**, 13(1), 7-14.

163. S. Iravani, H. Korbekandi, S. V. Mirmohammadi, B. Zolfaghari. Synthesis of silver nanoparticles: chemical, physical and biological methods, *Research in Pharmaceutical Sciences*, **2014**, 9(6), 385-406.

164. M. I. Skiba, V. I. Vorobyova, I. V. Kossogina. Preparation of silver nanoparticles in a plasma-liquid system in presence of PVA: antimicrobial, catalytic, and sensing properties, *Journal of Chemistry*, **2020**, 2020, 5380950.

165. W. K. A. W. M. Khalir, K. Shameli, S. D. Jazayeri, N. A. Othman, N. W. C. Jusoh, N. M. Hassan. Biosynthesized silver nanoparticles by aqueous stem extract of entada spiralis and screening of their biomedical activity, *Frontiers in Chemistry*, **2020**, 8(620), 1-15.

166. N. D. Hung, M. V. Phuoc, N. M. Thuy. The electrical conductivity of nano silver solution, *Journal of Military Science and Technology Research*, **2012**, 17(2), 96-111.

167. N. D. Hung, L. V. Hung, N. M. Thuy. Using of UV-Vis for metallic nanosilver solution prepared by anodic dissolution with untral-high voltage, *Journal of Military Science and Technology Research*, **2012**, 19(6), 94-99.

168. L. Ge, Q. Li, M. Wang, J. Ouyang, X. Li, M. M. Q Xing. Nanosilver particles in medical application: synthesis, performance, and toxicity, *International Journal of Nanomedicine*, **2014**, 9, 2399-2407.

169. G. Pedersen. *A fighting chance: how to win the war against virus and bacteria with silver*, Self-Published, New York, 2011.

170. G. Pedersen. *A new fighting chance: silver solution: a quantum leap in silver technology: how molecular structuring safely destroys bacteria, viruses and yeast*, CreateSpace Publishing, New York, 2014.

171. R. W. Y. Sun, R. Chen, N. P. Y. Chung, C. M. Ho, C. L. S. Lin, C. M. Che. Silver nanoparticles fabricated in Hepes buffer exhibit cytoprotective activities toward HIV-1 infected cells, *Chemical Communication*, **2005**, 28(40), 5059-5061.

172. H. H. Lara, L. I. Turrent, E. N. G. Treviño, C. R. Padilla. PVP-coated silver nanoparticles block the transmission of cell-free and cell-associated HIV-1 in human cervical culture, *Journal of Nanobiotechnology*, **2010**, 8, 15-25.

173. S. Galdiero, A. Falanga, M. Vitiello, M. Cantisani, V. Marra, M. Galdiero. Silver nanoparticles as potential antiviral agents, *Molecules*, **2011**, 16(10), 8894-8918.

174. Z. A. Ratan, F. R. Mashrur, A. P. Chhoan, S. M. Shahriar, M. F. Haidere, N. J. Runa, S. Kim, D. H. Kweon, H. Hosseinzadeh, J. Y. Cho. Silver nanoparticles as potential antiviral agents, *Pharmaceutics*, **2021**, 13(12), 2034.

175. J. V. Rogers, C. V. Parkinson, Y. W. Choi, J. L. Speshock, S. M. Hussain. A preliminary assessment of silver nanoparticles inhibition of monkeypox virus plaque formation, *Nanoscale Research Letters*, **2008**, 3, 129-133.

176. L. Lu, R. W. Y. Sun, R. Chen, C. M. Hui, C. M. Ho, J. M. Luk, G. K. K. Lau, C. M. Che. Silver nanoparticles inhibit hepatitis B virus replication, *Antiviral Therapy*, **2008**, 13, 253-262.

177. L. Sun, A. Singh, K. Vig, S. R. Pillai, S. R. Sing. Silver nanoparticles inhibit replication of respiratory syncytial virus, *Journal of Biomedical Nanotechnology*, **2008**, 4(2), 149-158.

178. D. B. Pinto, S. Shukla, N. Perkas, A. Gedanken, R. Sarid. Inhibition of herpes simplex virus type 1 infection by silver nanoparticles capped with mercaptoethane sulfonate, *Bioconjugate Chemistry*, **2009**, 20(8), 1497-1502.

179. J. L. Speshock, R. C. Murdock, L. K. B. Stolle, A. M. Schrand, S. M. Hussain. Interaction of silver nanoparticles with Tacaribe virus, *Journal of Nanobiotechnology*, **2010**, 8(19), 19-27.

180. C. T. T. Huyen, N. T. T. Binh, T. N. Duong, N. T. Hai. Nanosilver and prospects of medicinal applications, *VNU Journal of Science: Natural Sciences and Technology*, **2014**, 30(2), 23-32.

181. N. Hadrup, A. K. Sharma, K. Loeschner, N. R. Jacobsen. Pulmonary toxicity of silver vapours, nanoparticles and fine dusts: a review, *Regulatory Toxicology and Pharmacology*, **2020**, 115, 104690.

182. Y. S. Kim, J. S. Kim, H. S. Cho, D. S. Rha, J. M. Kim, J. D. Park, B. S. Choi, R. Lim, H. K. Chang, Y. H. Chung, I. H. Kwon, J. Jeong, B. S. Han, I. J. Yu. Twenty-eight-day oral toxicity, genotoxicity, and genderrelated tissue distribution of silver nanoparticles in Sprague-Dawley rats, *Inhalation Toxicology*, **2008**, 20(6), 575-583.

183. P. Mathur, S. Jha, S. Ramteke, N. K. Jain. Pharmaceutical Aspects of silver nanoparticles, *Artificial Cells, Nanomedicine, and Biotechnology*, **2018**, 46, 115-126.

184. N. R. Panyala, E. M. P. Méndez, J. Havel. Silver or silver nanoparticles: a hazardous threat to

the environment and human health? *Journal of Applied Biomedicine*, **2008**, 6(3), 117-129.

185. S. Kittler, C. Greulich, J. Diendorf, M. Koller, M. Epple. Toxicity of silver nanoparticles increases during storage because of slow dissolution under release of silver ions, *Chemistry of Materials*, **2010**, 22(16), 4548-4554.

186. L. V. Stebounova, A. A. Dodd, J. S. Kim, H. Park, P. T. O'Shaughnessy, V. H. Grassian, P. S. Thorne. Nanosilver induces minimal lung toxicity or inflammation in a subacute murine inhalation model, *Particle and Fibre Toxicology*, **2011**, 8(5), 5-17.

187. T. Zhang, L. Wang, Q. Chen, C. Chen. Cytotoxic potential of silver nanoparticles, *Yonsei Medical Journal*, **2014**, 55(2), 283-291.

188. E. M. Luther, Y. Koehler, J. Diendorf, M. Epple, R. Dringen. Accumulation of silver nanoparticles by cultured primary brain astrocytes, *Nanotechnology*, **2011**, 22, 375101.

189. W. Liu, Y. Wu, C. Wang, H. C. Li, T. Wang, C. Y. Liao, L. Cui, Q. F. Zhou, B. Yan, G. B. Jiang. Impact of silver nanoparticles on human cells: effect of particle size, *Nanotoxicology*, **2010**, 4(3), 319-330.

190. S. Barcikowski, P. Wagener, N. Bärsch. Ligandenfreie laser-generierte nano-partikel für biomedizin und katalyse, *BioPhotinik*, **2013**, 2, 34-37.

191. T. Mitsudome, A. Noujima, Y. Mikami, T. Mizugaki, K. Jitsukawa, K. Kaneda. Supported gold and silver nanoparticles for catalytic deoxygenation of epoxides into alkenes, *Angewandte Chemie*, **2010**, 49(32), 5677-5680.

192. P. Saha, M. Mahiuddin, A. B. M. N. Islam, B. Ochiai. Biogenic synthesis and catalytic efficacy of silver nanoparticles based on peel extracts of citrus macroptera fruit, *ACS Omega*, **2021**, 6(28), 18260-18268.

193. X. Y. Dong, Z. W. Gao, K. F. Yang, W. Q. Zhang, L. W. Xu. Nanosilver as a new generation of silver catalysts in organic transformations for efficient synthesis of fine chemicals, *Catalysis Science Technology*, **2015**, 5, 2554-2574.

194. L. S. Ardakani, A. Surendar, L. Thangavelu, T. Mandal. Silver nanoparticles (AgNPs) as catalyst in chemical reactions, *Synthetic Communications*, **2021**, 51(10), 1-21.

195. V. K. Shukla, R. S. Yadav, P. Yadav, A. C. Pandey. Green synthesis of nanosilver as a sensor for detection of hydrogen peroxide in water, *Journal of Hazardous Materials*, **2012**, 213-214, 161-166.

196. M. Zahran, Z. Khalifa, M. A. H. Zahrana, M. A. Azzema. Recent advances in silver nanoparticle-based electrochemical sensors for determining organic pollutants in water: a review, *Materials Advances*, **2021**, 2(22), 7350.

197. I. Ivanišević. The role of silver nanoparticles in electrochemical sensors for aquatic environmental analysis, *Sensors*, **2023**, 23(7), 3692.

198. I. Shah, R. Adnan, W. S. W. Ngah, N. Mohamed. A review of the use of silver nanoparticles in environment, *International Journal of Chemistry*, **2014**, 35(1), 1459-1471.

199. L. T. N. Hoa, T. Q. Minh, H. T. Kha, V. N. An. *Synthesis and evaluation of the antibacterial activity of silver nanoparticles in indoor waterborne architectural coating*, *Can Tho University Journal of Science*, **2021**, 57(3A), 10-22.

200. B. Barman, H. Dhasmana, A. Verma, A. Kumar, D. N. Singh, V. K. Jain. Fabrication of silver nanoparticles on glass substrate using low-temperature rapid thermal annealing, *Energy & Environment*, **2018**, 29(3), 358-371.

201. D. Roe, B. Karandikar, N. B. Savage, B. Gibbins, J. B. Roullet. Antimicrobial surface functionalization of plastic catheters by silver nanoparticles, *Journal of Antimicrobial Chemotherapy*, **2008**, 61(4), 869-876.

202. A. Sadeghnejad, A. Aroujalian, A. Raisi, S. Fazel. Antibacterial nano silver coating on the surface of polyethylene films using corona discharge, *Surface & Coatings Technology*, **2014**, 245, 1-8.

203. C. Lambré, J. M. B. Bavier, C. Bolognesi, A. Chesson, P. S. Cocconcelli, R. Crebelli, D.

M. Gott, K. Grob, E. Lampi, M. Mengelers, A. Mortensen, I. L. Steffensen, C. Tlustos, H. V. Loveren, L. Vernis, H. Zorn, L. Castle, E. D. Consiglio, R. Franz, N. Hellwig, S. Merkel, M. R. Milana, E. Barthélémy, G. Rivière. Safety assessment of the substance silver nanoparticles for use in food contact materials, *EFSA Journal*, **2021**, 19(8), 06790.

204. L. H. Tien. *Research on the preparation of chitosan - nano silver applied in post-harvest preservation of fruits*, PhD thesis, Hanoi University of Science and Technology, 2019.

205. N. B. Trung. *Research on synthesis of nano-silver-chitosan combination products for post-harvest preservation of dragon fruit*, PhD thesis, University of Danang, 2016.

206. N. H. D. Tuan. *Research on fabrication of chitosan - nano silver film and initial experiment in preserving Hoa Loc mango*, PhD thesis, Can Tho University, 2014.

207. H. Chen, G. Zhang, W. Zhang, W. Gao. Silver nanoparticles deposited on a cotton fabric surface *via an in situ* method using reactive hyperbranched polymers and their antibacterial properties, *RSC Advances*, **2023**, 13(17), 11450-11456.

208. M. F. Chaplin. Water: its importance to life, *Biochemistry and Molecular Biology Education*, **2001**, 29(2), 54-59.

209. S. S. Ratnupadi, M. Fürhacker. Review: issues of silver nanoparticles in engineered environmental treatment systems, *Water, Air & Soil Pollution*, **2014**, 225, 1939.

210. C. Forstner, T. G. Orton, P. Wang, P. M. Kopittke, P. G. Dennis. Wastewater treatment processing of silver nanoparticles strongly influences their effects on soil microbial diversity, *Environmental Science & Technology*, **2020**, 54(21), 13538-13547.

211. G. Palani, H. Trilaksana, R. M. Sujatha, K. Kannan, S. Rajendran, K. Kornienko, M. Nykiel, M. Uthayakumar. Silver nanoparticles for waste water management, *Molecules*, **2023**, 28(8), 3520.

212. A. Fiorati, A. Bellingeri, C. Punta, I. Corsi, I. Venditti. Silver nanoparticles for water pollution monitoring and treatments: ecosafety challenge and cellulose-based hybrids solution, *Polymers*, **2020**, 12(8), 1635.

213. N. T. Kien, T. T. T. Huong, N. H. Chau, D. D. Kim, D. T. Thuy. Size effect of copper nanoparticles on *microcystis aeruginosa*, *Vietnam Journal of Biotechnology*, **2018**, 16(2), 361-367.

214. P. H. Lam, M. T. Le, D. M. T. Dang, T. C. Duc Doan, N. P. C. Tu, C. M. Dang. Safe concentration of silver nanoparticles in solution for white leg shrimp (*litopeaneus vannamei*) farming, *Biological and Chemical Research*, **2020**, 7, 35-45.

215. L. C. Jiménez, A. R. A. Sánchez, C. H. M. Ruiz. Silver nanoparticles (AgNPs) as antimicrobials in marine shrimp farming: a review, *Aquaculture Reports*, **2020**, 18, 100512.

216. T. S. Le, T. H. Dao, D. C. Nguyen, H. C. Nguyen, I. L. Balikhin. Air purification equipment combining a filter coated by silver nanoparticles with a nano-TiO<sub>2</sub> photocatalyst for use in hospitals, *Advances in Natural Sciences: Nanoscience and Nanotechnology*, **2015**, 6, 015016.

217. R. Parameshwaran, S. Kalaiselvam. Energy conservative air conditioning system using silver nano-based PCM thermal storage for modern buildings, *Energy and Buildings*, **2014**, 69, 202-212.

218. M. E. Quadros, L. C. Marr. Environmental and human health risks of aerosolized silver nanoparticles, *Journal of the Air Waste Management Association*, **2010**, 60(7), 770-781.

219. E. Jankowska, J. Lukaszewska. Potential exposure to silver nanoparticles during spraying preparation for air-conditioning cleaning, *Medycyna Pracy*, **2013**, 64(1), 57-67.

220. L. Ge, Q. Li, M. Wang, J. Ouyang, X. Li, M. M. Q Xing. Nanosilver particles in medical applications: synthesis, performance, and toxicity, *International Journal of Nanomedicine*, **2014**, 9, 2399-2407.

221. T. D. Binh, T. T. Loan. Initial results of study on silver nanoparticles concentration applied in hospital infection, *Journal of Medicine and Pharmacy - Hue University of Medicine and Pharmacy*, **2021**, 9, 26-30.

222. S. Johaley, F. Karjodkar, P. Kaustubh, Sansare, S. Sharma, M. Saalim. Silver nanoparticles: new diagnostic and therapeutic approach in treatment of oral diseases, *European Journal of Pharmaceutical and Medical Research*, **2018**, 5(6), 239-244.

223. E. A. A. Neel, L. Bozec, R. A. Perez, H. W. Kim, J. C. Knowles. Nanotechnology in dentistry: prevention, diagnosis, and therapy, *International Journal of Nanomedicine*, **2015**, 10, 6371-6394.

224. P. Takáč, R. Michalková, M. Čižmáriková, Z. Bedlovičová, L. Balážová, G. Takáčová. The role of silver nanoparticles in the diagnosis and treatment of cancer: are there any perspectives for the future?, *Life*, **2023**, 13, 466.

225. P. Mathur, S. Jha, S. Ramteke, N. K. Jain. Pharmaceutical aspects of silver nanoparticles, *Artificial Cells, Nanomedicine, and Biotechnology*, **2018**, 46, 115-126.

226. V. L. Li. *Advancing silver nanostructures towards antibacterial applications*, PhD thesis, RMIT University, 2014.

227. X. Chen, H. J. Schluesener. Nanosilver: a nanoproduct in medical application, *Toxicology Letters*, **2008**, 176, 1-12.

228. M. Konop, T. Damps, A. Misicka, L. Rudnick. Certain aspects of silver and silver nanoparticles in wound care: a minireview, *Journal of Nanomaterials*, **2016**, 2016, 7614753.

229. F. Paladini, M. Pollini. Antimicrobial silver nanoparticles for wound healing application: progress and future trends, *Materials: Basel*, **2019**, 12(16), 2540.

230. R. Pangestika, R. Ernawati, Suwarno. *Antiviral activity effect of silver nanoparticles (AgNPs) solution against the growth of infectious bursal disease virus on embryonated chicken eggs with elesa test*, The Veteribary Medicine International Conference, VMIC 2017, East Java, Indonesia, 2017.

231. E. O. Mikhailova. Silver nanoparticles: mechanism of action and probable bio-application, *Journal of Functional Biomaterials*, **2020**, 11(4), 84.

232. R. R. Koyale, I. L. Patel, S. D. Pingale. Detection of cholera toxin using lactose-decorated silver nanoparticles, *Science and Technology*, **2018**, 4(2), 902-906.