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Sterilization Device Using Silver Nanoparticles

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Abstract

Silver nanoparticles (Ag NPs) interact with both the surface and structural proteins of viral or bacterial cells, leading to destruction of the pathogenic cells or disruption of their metabolic processes. One of the benefits of using Ag NPs as sterilants is their inability to be adapted to by pathogenic cells, unlike traditional sterilization methods. While silver is generally non-toxic to human health, prolonged exposure can result in a condition known as argyria, characterized by blue discolouration of the skin. The proposed device utilizes Ag NPs for external sterilization of individuals entering a room measuring approximately (1 × 1 × 2) meters, through the release of a batch of steam. Ultrasonic vaporizers utilize a piezoelectric transducer to convert electrical energy into mechanical vibrations, which agitate the water stored within the device. This results in the production of water vapour infused with silver nanoparticles (Ag NPs) that are dissolved in the water. The silver nanoparticles possess antimicrobial properties, allowing the vapour to effectively sterilize the user by eliminating infectious agents present on the skin, hair, or clothing. The use of ultrasonic vaporizers in crowded areas can help to reduce the spread of infectious diseases, such as SARS-CoV-2 and influenza. Additionally, ultrasonic vaporizers are easy to operate and do not require specialized expertise, making them a suitable option for use outside of healthcare facilities.

1. Introduction

In the contemporary era, the importance of sterilization has become increasingly paramount, particularly in light of the expansion of healthcare and its prioritization in various nations. With the advancements in medicine, surgery, and healthcare provision, sterilization is no longer confined to the medical field alone. In modern hospitals, a specialized section, known as the sterilization department, is designated to sterilize all medical instruments within the facility. Sterilization is a process that eliminates all microorganisms on a surface or in a liquid, thereby reducing the risk of disease transmission associated with the use of that item. Traditional sterilization methods, such as steam sterilization or dry heat, have several limitations, including the inability to sterilize materials that cannot tolerate high temperatures, and the inability to sterilize vital materials and living tissue as they can cause harm. Therefore, there is a need to explore new sterilization methods that do not have these drawbacks and are more effective against pathogens, such as silver nanoparticles. In this research, we propose a device that utilizes silver nanoparticles as a sterilizer, providing the highest level of effectiveness against

bacteria, germs, fungi, and viruses. Additionally, the device features sensors that give an alarm in the event of an error, to ensure the safe operation of the device and the gentle delivery of the sterile material to the target area, and an easy-to-use and almost automatic operation method for the operator.

2. Theoretical Part

2.1. Silver Ion (Ag+)

A silver atom, upon losing an electron from its orbital shells, becomes positively charged and thus forms an unstable ion. This instability results in a state of constant reactivity, allowing the ion to regain stability through the acquisition of an additional electron [1]. **Silver nanoparticles:** Also known as Ag NPs are nanoscale stable crystallites composed of several thousand silver atoms [1]. They possess various forms, including spherical, triangular, and irregular, which are dependent on the method of synthesis utilized [2]. Synthesis of these particles can be achieved through various techniques, including chemical and biological methods, with a range of sizes from 1 to 100 nanometers. The high surface area to volume ratio of these particles confers them with antimicrobial properties, in addition to enhancing their nanoscale physical and chemical properties that further augment their activity [3].

2.2. The Distinction between Silver Ions and Silver Nanoparticles

Ions consistently exhibit a proclivity for gaining an additional electron in order to attain stability, which subsequently results in a rapid diminishment of their activity and loss of antimicrobial properties. In contrast, silver nanoparticles possess a greater degree of stability as they do not possess a deficient electron and do not engage in interactions with other materials, thus preserving their antimicrobial properties for a prolonged duration [1].

Table (1). The primary distinctions between silver nanoparticles (Ag NPs) and silver ions (Ag+) [1].

Difference	Ag^+	Ag NPs
Appearance	One silver atom without an electron	Several thousand silver atoms combined into tiny crystals
Chemical activity	Active chemically (active to add an electron)	Inactive chemically
Work mechanism	Acts as a toxin	Destroys cell wall
Action duration	Quickly loses its activity after the interaction	Effective for a long period
Bacterial adaptation methods	Adapt	Not yet discovered
Penetrating the dermis of the skin	Most ions cannot penetrate	It penetrates the dermis due to its nano size
Special compound coatings	No	Coated with active ingredients

Based on the available evidence, it can be inferred that the utilization of silver nanoparticles exhibits superior efficacy, efficiency, and safety in comparison to silver ions. Furthermore, silver nanoparticles are better suited for their intended purpose and demonstrate a prolonged period of effectiveness [1].

2.3. The Method of Sterilization for Each Silver Ions and Silver Nanoparticles

Silver ions have been found to effectively inhibit the vital functions of microorganisms by entering and spreading within the cells and acting as a poison to ultimately kill them [1]. This is achieved through the inhibition of food channels and the disruption of cell membrane integrity, as well as the destruction and inactivation of thiol enzymes and other cellular compounds [3]. However, it should be noted that the effectiveness of silver ions is limited by the need for a high concentration at the site of infection and the potential for microorganisms to develop resistance [1, 3]. Additionally, it has been found that nanoparticles may provide a more effective alternative as microorganisms are less able to develop resistance against them [3]. **Silver Nanoparticles (Ag NPs)** exhibit a unique mechanism of action in which they disrupt the cell membrane of bacteria, resulting in immediate cellular

death. This differs from the mode of action of ions, which induces toxicity through the release of toxins. The rapid demise of the microorganisms precludes the possibility of the development and transmission of resistance mechanisms, as the cells do not survive long enough to undergo decomposition and release the nanoparticles for further rounds of antimicrobial activity [1]. A study on P. aeruginosa demonstrated that Ag NPs possess the ability to circumvent the immunity mechanisms developed by bacteria and spores against silver. This immunity is achieved through the inhibition of silver ions from entering the cytoplasm. Furthermore, the study revealed that Ag NPs exhibit multiple mechanisms for resisting this immunity, including the destruction of pre-existing biofilms, as well as the reduction of flagellum motility and biofilm formation [4]. The application of a silver nanoparticle coating on the surface serves a dual purpose: it functions as a protective barrier while simultaneously serving as a vehicle for the transport of active agents [1]. The mechanism by which silver nanoparticles (Ag NPs) exert their inhibitory effect on the growth or eradication of microorganisms is not yet fully understood, despite evidence of their potent antibacterial activity against both Gram-positive and Gram-negative bacteria. Various experiments have demonstrated that the physical and chemical properties of Ag NPs, such as surface characteristics and size, play a role in facilitating the penetration of molecules through the cell membrane and impacting internal cellular components [5]. Recent experimental studies have established the existence of three distinct mechanisms by which silver nanoparticles (Ag NPs) exhibit antibacterial activity [6]. The first hypothesis is that the molecules work to destabilize and damage the cell by penetrating the outer wall and accumulating on the inner wall, where the permeability of the shell increases and leakage of the cellular content occurs outside the cell [5]. Interactions between molecules and elements containing sulfur within the cell wall can result in cellular damage and the disruption of the integrity of the cell wall [5]. The second mechanism posits that, in addition to the first, Ag NPs possess the capability to interact with sulfur and phosphorus, which are integral components of internal proteins and cellular DNA, due to their strong reactivity. This interaction results in the alteration of the structure and function of these biomolecules [5]. It is proposed that molecules in the inner membrane may interact with thiol groups present in enzymes responsible for catalyzing the production of reactive oxygen species and free radicals, resulting in damage to respiratory mechanisms and cellular demise. Additionally, it is hypothesized that the release of free silver ions (Ag^+) as products of these reactions may occur simultaneously, further disrupting cellular respiration, metabolic processes, and genetic pathways through interactions with intracellular proteins [5].

2.4. The Antibacterial Properties of Silver Nanoparticles (Ag NPs)

Previous studies have demonstrated that silver nanoparticles (Ag NPs) possess a potent biocidal effect against a diverse range of bacteria, including both Gram-negative and Gram-positive strains. In order to evaluate this effectiveness, Sondi and Salopeck-Sondi conducted an experiment using strains of E.coli as a model for Gram-negative bacteria. The results revealed that the initial bacterial concentration and the concentration of molecules play a significant role in the inhibition process, which occurs through three stages: Firstly, particles with a size range of 1 – 10 nm disrupt basic cellular functions, such as permeability and respiration, after adhesion to the outer surface of the bacterial cell [7]. Secondly, its capability to permeate the bacterial cell membrane and interact with the sulfur and phosphorus compounds present in DNA [7]. Third, Ag NPs release Ag^+ ions as a result of these reactions, which also exert an antimicrobial effect. Thereby enhancing the overall effectiveness of Ag NPs against bacteria [7].

2.5. Factors, Including Concentrations and Synthesis Methods, which Influence the Antibacterial Efficacy of Silver Nanoparticles

The antibacterial activity of Ag NPs is influenced by various factors, including mechanical properties as well as chemical volume and surface charge. It has been observed that particles with a size of 5 nm exhibit a greater antibacterial effect. The minimum inhibitory concentrations for all tested microorganisms were found to be in the range of 25-50 μg/L, with the exception of the E. coli strain. The pneumonic nature of E. coli limits the ability of Ag NPs to effectively inhibit its growth, as exposure to air in aqueous medium results in the oxidation of molecules, leading to a lower minimum inhibitory concentration of 6 μg/L [5]. In a separate experiment, silver nanoparticles (Ag NPs) of varying sizes from 5 to 100 nanometers were synthesized using consistent agents and protocols, with variations in pH conditions, reducing agent ratios, and reaction stability. The resulting Ag NPs were subsequently evaluated for their antibacterial properties against Gram-negative bacteria through the determination of minimum inhibitory concentrations (MICs). The MICs for the strains of Escherichia coli, Bacillus subtilis, and Staphylococcus aureus were observed to range as follows: {a (20-110), b(30-120), c(60-160), d(70-200)}. It was determined that the antibacterial activity of the Ag NPs is heavily dependent on surface factors, with smaller

particle sizes resulting in increased surface area available for interaction with bacterial cells [5]. In a third study, silver nanoparticles of varying sizes were synthesized via chemical reduction methods and their growth inhibitory activity was evaluated against strains of Escherichia coli and Pseudomonas aeruginosa. The results indicated that nanoparticles with dimensions ranging from 15 to 50 nanometers exhibited an inhibition rate of 8 millimetres for P. aeruginosa growth, while for E. coli the inhibition rate was only 1.5 millimetres. Conversely, particles larger than 30-200 nanometers displayed low inhibition rates when compared to their smaller counterparts, with an inhibition rate of 0.7 millimetres for E. coli and 0.8 millimetres for P. aeruginosa. A similar trend was observed in a subsequent study utilizing laser-generated silver nanoparticles, where an inverse association was found between inhibitory effectiveness against E. coli and the size of the nanoparticles. The optimal size for inhibitory effectiveness was determined to be 19 nanometers, with the researchers determining that the small size of the nanoparticles increased the production of reactive oxygen species, thereby enhancing inhibitory effectiveness [8]. The charge factor has been found to play a significant role in the inhibitory activity of positively charged silver nanoparticles Ag NPs. According to the research conducted by Abbaszadegan et al., it is suggested that the antibacterial efficacy of Ag NPs is attributed to the electrostatic attraction between the positively charged nanoparticles and the negatively charged bacterial cells [5]. It can be posited that the size of nanoparticles plays a significant role in determining the contact area and interaction with the surrounding medium. Conversely, the charge and surface composition of the nanoparticles are key factors in determining the stability of the particles during interaction. If the stability of the nanoparticles is low, they tend to aggregate, resulting in decreased antibacterial efficacy. Utilizing the Zeta potential as a measure of stability, it can be inferred that the most stable nanoparticles are those whose surface charge is greater than +30 mV or less than -30 mV, as this prevents unwanted interactions and minimizes the formation of agglomerates. This can be achieved through manipulation of the synthesis process and choice of surface coating agents [9]. Empirical observations have demonstrated that the dissolution rate of nanoparticles in various media exhibits an inverse relationship with the size of the particles. As such, the rate of release of silver ions from small JCMAT particles is found to be higher, with these ions also playing a significant role in inhibiting bacterial growth upon release [5].

2.6. The Antifungal Properties of Silver Nanoparticles (Ag NPs)

Fungi are a significant source of pathogenic infections, particularly in healthcare settings. Despite this, there is a lack of comprehensive research on the antifungal efficacy of silver nanoparticles (Ag NPs). A study conducted by Kim et al. evaluated the antifungal activity of Ag NPs against 44 strains of 6 different fungal species, including clinical isolates and ATCC strains of Trichophyton mentagrophytes and Candida albicans. The results of the study revealed an inhibition ratio of 80% (IC80) at a concentration range of 1 to 7 mg/L. The Ag NPs were found to be effective against C. albicans by disrupting the cell membrane and inhibiting the budding process [7]. Roe et al. conducted a study to evaluate the antifungal activity of plastic catheters coated with silver nanoparticles (Ag NPs) with a thickness of 100 nm. The results demonstrated near-total inhibition of Candida albicans. In a separate investigation, Pamacek et al. examined the antifungal properties of Ag NPs prepared using the modified Tollens process. The results revealed that the minimum inhibition rate of C. albicans was 0.21 mg/L when using unmodified Ag NPs, and 0.05 mg/L when using modified Ag NPs in combination with sodium dodecyl sulfate (SDS) [7]. The utilization of silver nanoparticles at a concentration of 30 mg/L effectively suppressed the proliferation of various yeast strains at concentrations that did not elicit cytotoxicity against human fibroblast cells. [7]. It has been reported by various sources that silver nanoparticles exhibit minimum inhibitory concentrations (MICs) ranging from 0.4-3.3 mg/L against Candida albicans and Candida glabrata, and a MIC of 10 mg/L against Trichophyton rubrum. It can be inferred from this data that silver nanoparticles possess fungicidal properties and may be an effective treatment for fungal infections in humans [7].

2.7. The Antiviral Properties of Silver Nanoparticles (Ag NPs) as a Potential Therapeutic Agent

In a recent literature review, the utilization of nanomaterials composed of silver and copper as antiviral agents was highlighted with a specific emphasis on SARS-CoV-2 [10]. A subsequent study demonstrated that low concentrations of (Ag NPs) can be utilized as a non-toxic agent, It has been determined through research that Ag NPs, with a diameter of approximately 10 nanometers, exhibit toxic effects on cells at concentrations of 20 parts per million and above. Conversely, these Ag NPs have been found to inhibit extracellular SARS-CoV-2 at concentrations between 1 and 10 parts per million [11]. The binding of the spike protein to the ACE2 receptor in SARS CoV-2 is facilitated by the presence of disulfide bonds. It is proposed that the use of Ag NPs, through their ability to interact with viral nucleic acids and block this binding, may represent a potential strategy for combating

the virus [11]. Furthermore, it has been demonstrated that Ag NPs possess the capability to not only inhibit, but also inactivate a variety of viruses, including but not limited to SARS-CoV-2, monkeypox virus, HIV-1, hepatitis B, and certain strains of influenza viruses [12]. In a study conducted by Elechiguerra et al., the impact of nanoparticles on HIV-1 was evaluated. The findings of the study revealed that the size of the nanoparticles plays a crucial role in determining their effectiveness, with smaller particles exhibiting a greater impact. Additionally, the study also highlighted the significance of the nanoparticles' ability to interact with sulfur in the glycoprotein gp120, which can disrupt the function of the protein [7]. In a recent study, another group of researchers reported that the mechanism of interaction with sulfur is also effective in inhibiting the replication of HIV. Furthermore, Sun et al. in their published article highlighted the significant role of silver nanoparticles (Ag NPs) in inhibiting the synthesis of RNA of hepatitis B virus (HBV) and extracellular viruses in vitro. Their research work also involved conducting experiments using polyvinylpyrrolidone (PVP)-coated Ag NPs in combination with a protein to combat respiratory syncytial virus (RSV)-induced infection in Hep-2 cells. The results demonstrated the effectiveness of this approach in combating viral infections [7]. Despite the fact that the findings of all studies suggest that Ag NPs are associated with the viral cell's external proteins, they have yet to be established as a dependable mechanism. Nonetheless, silver nanoparticles are considered a significant research material in the future due to their potential in combating viral diseases and infections [7].

3. Synthesis of Silver Nanoparticles

In the course of our investigation, it was determined that silver nanoparticles exhibit variations in shape depending on the synthesis method employed, with each distinct form possessing unique characteristics that render it effective against pathogens. Synthesis techniques can be broadly categorized into four primary categories, namely: Physical methods, chemical methods, photochemical synthesis, and green (biological) synthesis. Each of these categories has its own advantages and disadvantages, and within each category, there exists a multitude of specific methods. It was found that among the methods of chemical synthesis, Chemical Reduction was particularly effective in producing a diverse array of silver nanoparticle shapes [13].

3.1. Physical Methods

Physical synthesis methods, which include Evaporation and Condensation, Laser ablation, Electric radiation, Gamma irradiation, and Lithography, have been widely utilized for the production of Ag NPs [13].

3.2. Chemical Methods

Chemical synthesis techniques, such as Chemical Reduction, Microemulsion Technologies, and Microwave-assisted Techniques, are utilized for the production of silver nanoparticles. The chemical reduction method was utilized to synthesize various forms of silver nanoparticles, as depicted in Figure (1). These forms include spherical silver particles, silver nanorods, silver nanowires, cubic silver nanoparticles, and triangular silver nanoparticles. [13].

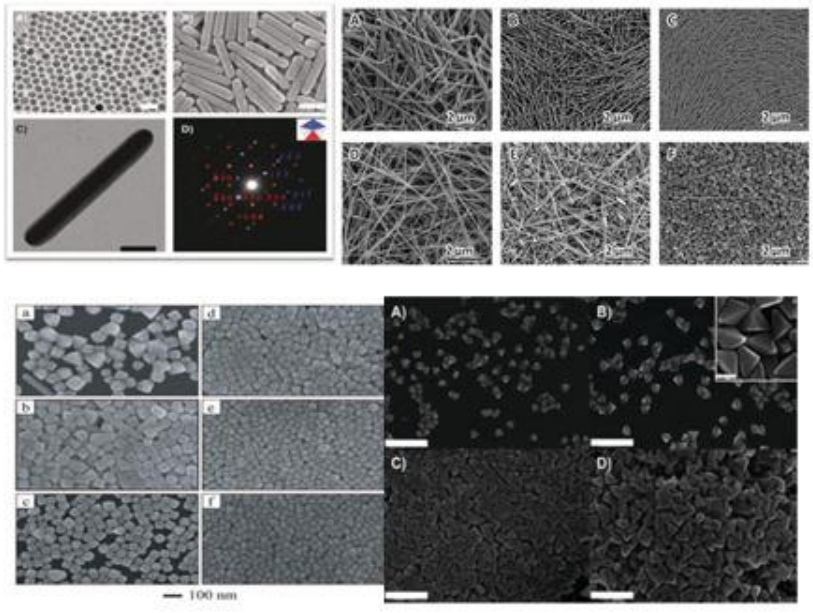

Figure (1). Various forms of silver nanoparticles that were synthesized via the Chemical Reduction method [13].

3.3. The Ramifications of Ag NPs on Human Well-being

In the examination of the impact of silver nanoparticles on human overall well-being, the factors of surface area and volume are of significant relevance. Three modes of exposure to silver particles have been identified: oral, inhalation, and cutaneous. Due to the minuscule dimensions of Ag NPs, they possess the capability to permeate the human epidermis with ease. Numerous investigations have been conducted on the impact of molecules ranging in size from 1 to 100 nanometers on human health, with limited findings. However, sub-chronic skin exposure to these molecules has been observed to result in an accumulation in the liver and lungs. Additionally, animal studies have demonstrated that such molecules can lead to pathological changes in the liver, spleen, skin and potentially muscle tissue as well. While research on the human body's response to silver nanoparticles (Ag NPs) is currently limited, it is clear that significant toxicity resulting from exposure to these particles is likely to occur only following prolonged and significant exposure. Further investigation is necessary in order to fully understand the potential effects of Ag NPs on the human body, and it is recommended that future studies utilize a variety of different sizes and shapes of Ag NPs in order to gain a comprehensive understanding of these effects and to ensure the safe and responsible use of these particles [14].

4. Results and Discussion

In this study, we discovered that silver nanoparticles possess potent properties against a diverse array of pathogens. We presented a summary of their mechanisms of action against the majority of these pathogens and explained that through appropriate synthesis methods, these particles can be manipulated in terms of concentration, size, and shape to enhance their efficacy against specific pathogens. This allows for titration of the silver nanoparticles against a specific pathogen, such as the inhibition and elimination of SARS-CoV-2. We proposed a device that utilizes silver nanoparticles in various concentrations and forms for external sterilization of pathogens and microorganisms on the patient's body. Our primary focus was on the development of a method to deliver the concentrated homogenate of the sterilizing agent to the target area without altering the properties of the sterilizing agent.

4.1. A Sterilization Device Utilizing Silver Nanoparticles

Efforts were undertaken to incorporate Nano-sterilization techniques within a streamlined apparatus designed for external sterilization of the user. This device has potential applications in various settings, particularly in areas characterized by high population density and thus increased transmission risk of infection. However, its utilization in healthcare facilities is particularly crucial, given the high level of sterilization required within these environments due to the presence of immunocompromised patients and those with open wounds who are particularly susceptible to airborne pathogens, particularly in intensive care units.

4.2. Device Definition

The Nano Sterilization Device is designed for external decontamination of individuals entering a room measuring approximately 1 meter by 1 meter by 2 meters. The device utilizes a burst of steam infused with silver nanoparticles, which is directed towards the individual for the purpose of eliminating harmful microorganisms such as viruses, bacteria, and other pathogens that may be transmitted through air or direct contact among hospital staff and visitors, as well as between these individuals and patients. This device functions by mixing silver nanoparticles with water that is stored in its reservoir, and then evaporating the mixture and applying it externally to the individual, thereby allowing the silver nanoparticles to effectively eradicate pathogens present on the individual's skin, hair, or clothing. This ultimately serves to enhance the overall level of protection within the hospital setting.

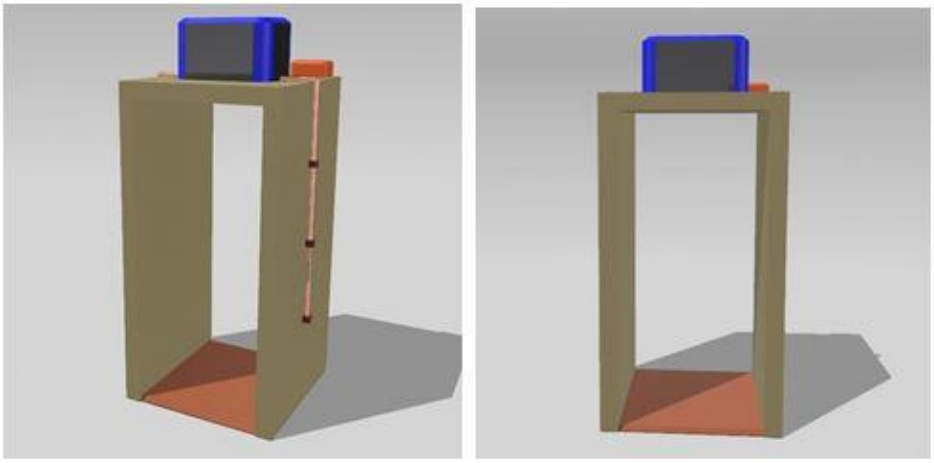

Figure (2). A three-dimensional model showing the design of the device.

4.3. Components of the Device

The system comprises of a combination of controllers, sensors, and electronic components. The controllers used in this system are Arduino Nano, and the sensing device is an HC-SR04 Ultrasonic sensor which has a detection range of up to 5 meters. The system also employs a 5V Single-Channel Relay Module, an Ultrasonic Evaporator, and light-emitting diodes (LEDs) of blue and white colour. Additionally, the system includes a water tank, as well as tubes for water circulation. These components work together to sense movement and changes in distance within specified range and activate the ultrasonic evaporator to release water vapour and control the colour of the LEDs.

4.4. Device Working Principle

The objective of the sterilization procedure is located within the equipment room, with dimensions measuring 1 meter by 1 meter by 2 meters. The ultrasonic sensor detects alterations in distance and transmits a signal to the controller. The controller subsequently emits two signals: the first signal initiates a change in the lighting colour to indicate the initiation of the sterilization process, and the second signal initiates the operation of the ultrasonic evaporators. The evaporators are affixed to the surface of tubes that are connected to the primary tank, in which a mixture of water and silver nanoparticles is stored. Upon receipt of the signal from the controller, the evaporators activate and generate steam saturated with silver nanoparticles, which subsequently fall upon the skin and penetrate the clothing of the individual in question. Additionally, the device includes a sensor measuring the level of the mixture within the tank, which transmits a signal to the controller when the tank becomes empty. The controller subsequently issues a warning to the user in the form of flashing lights and prevents the evaporators from operating to avoid any malfunction until the tank is refilled.

5. Conclusions

In this study, it was determined that silver nanoparticles possess antibacterial properties that can be summarized in three stages: first, nanoparticles within the range of 1-10 nm disrupt essential cellular functions such as permeability and respiration upon adhesion to the outer surface of the bacterial cell [4]. Secondly, the ability of the nanoparticles to penetrate the bacterial cell wall and react with sulfur- and phosphorus-containing DNA [4].

Thirdly, the release of Ag+ silver ions as a product of these reactions also possesses anticonvulsant effects and enhances the effectiveness of silver nanoparticles against bacteria [4]. Additionally, it can be stated that silver nanoparticles possess fungicidal properties and can be utilized as an effective treatment for fungal infections in humans [4]. Furthermore, the effectiveness of silver nanoparticles against viruses such as SARS-CoV-2, HIV-1, and Hep-2 has been established, though this effect may vary based on factors such as particle size, diameter, and method of synthesis, charge, coating, concentration, and the type of target organism. Therefore, to customize sterile materials for the sterilization of specific germs or viruses, it is possible to manufacture and calibrate the particles in regards to size, shape, diameter, charge, and concentration to optimize effectiveness against the target particle. In regards to the proposed Nano-sterilization device, the method for delivering silver nanoparticles and distributing them in a homogeneous manner (via ultrasonic vaporizers) was selected, and a plan was developed to design the device for use in sterilizing both medical instruments and individuals, with an emphasis on the latter. The device is equipped with the necessary safety features and is presented as a method for sterilization utilizing nanoparticles. Further testing and modifications can be performed to improve the quality of the device and increase the rate of transmission and distribution of sterilizing particles, as well as to optimize the sterilization rate.

Conflict of Interest: The authors declare that there are no conflicts of interest associated with this research project. We have no financial or personal relationships that could potentially bias our work or influence the interpretation of the results.

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