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Influence of Stirring Time on the Electrochemical Synthesis of Silver Nanoparticles: Size and Stability Analysis

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A B S T R A C T

This study explores the impact of stirring time on the size distribution and stability of silver nanoparticles (Ag-NPs) synthesized through an electrochemical method. High-purity silver rods and distilled water were used in an electrochemical cell, with varying stirring times (30 minutes and 1 hour) to observe differences in nanoparticle formation. UV-Visible spectrophotometry revealed characteristic plasmon resonance peaks at 395 nm for 30-minute stirring and 400 nm for 1-hour stirring, indicating differences in size distribution. Scanning Electron Microscopy (SEM) analyses showed that nanoparticles with a 30-minute stirring time had sizes ranging from 40 to 60 nm, while those with a 1-hour stirring time ranged from 30 to 50 nm. These findings underscore the importance of stirring time in achieving desired nanoparticle characteristics, which is crucial for applications in medical devices, coatings, and antimicrobial treatments.

Keywords: Silver nanoparticles (Ag-NPs), Electrochemical synthesis, Surface plasmon resonance (SPR)

1. Introduction

Nanostructured materials have garnered significant research interest due to their unique size-dependent physical and chemical properties. Among these materials, silver nanoparticles (Ag-NPs) are particularly noteworthy because of their exceptional antimicrobial properties, making them invaluable in medical and industrial applications. Historically, silver has been used as a disinfectant and in clinical treatments for its potent antibacterial properties and low toxicity to mammalian cells. Consequently, silver is utilized in various forms such as creams, solutions, electrodes, ligatures, biological skins, and catheters.

The synthesis of metal nanoparticles, including Ag-NPs, has been extensively studied due to their distinctive chemical and physical properties. These nanoparticles offer potential applications in areas such as catalysis, electronics, and medicine. Silver nanoparticles, in particular, have been recognized for their remarkable antimicrobial efficacy against a wide range of microorganisms, including bacteria, viruses, and fungi. This has led to their use in medical devices, coatings, and textiles to prevent infections and contamination [1].

Silver's use as an antimicrobial agent date back to ancient civilizations, where it was employed to prevent infections and preserve liquids. Modern interest in silver nanoparticles stems from their high surface area to volume ratio, which enhances their physical and chemical properties compared to bulk silver. The ability of silver nanoparticles to disrupt microbial cell membranes and interfere with cellular metabolism makes them highly effective at low concentrations, reducing the risk of toxicity to human cells.

Electrochemical synthesis methods are particularly attractive for producing silver nanoparticles due to their simplicity, cost-effectiveness, and the ability to control the size and distribution of the particles by adjusting various parameters such as voltage, current, and stirring time. This method also minimizes the use of hazardous chemicals, aligning with the principles of green chemistry.

The synthesis of silver nanoparticles through electrochemical methods has been well documented. Kharissova et al. (2013) highlighted the greener synthesis approaches for nanoparticles, emphasizing the importance of environmentally friendly methods in nanoparticle production. Similarly, Carma (2012) discussed sustainable applications and the greener synthesis of nanomaterials, which aligns with the electrochemical synthesis methods used in our study [2,3].

Studies have shown that the size and morphology of silver nanoparticles can be controlled by adjusting the synthesis parameters. Blandón et al. (2012) investigated the electrochemical synthesis of silver nanoparticles and demonstrated the effect of different experimental conditions on the size distribution of the nanoparticles. Lei and Yang (2007) also studied the synthesis of nano-silver colloids and found that parameters such as voltage, stirring time, and temperature significantly influenced the properties of the resulting nanoparticles [4,5].

In terms of applications, Zhao and Stevens (1998) explored the antimicrobial properties of silver nanoparticles and their potential uses in biomedical applications [6]. Their research indicated that silver nanoparticles exhibit strong bactericidal activity while maintaining low toxicity to human cells. This dual functionality makes them ideal for use in medical devices and treatments to prevent infections [7-11].

Despite the extensive research on the synthesis and applications of silver nanoparticles, there is a notable gap in the detailed understanding of the effects of stirring time on the size distribution and stability of silver nanoparticles synthesized using electrochemical methods. While several studies have focused on the impact of various synthesis parameters such as voltage and temperature, the specific influence of stirring time has not been comprehensively explored. This research aims to fill this gap by systematically investigating how different stirring times affect the formation, size distribution, and stability of silver nanoparticles.

2.Materials and Methods

2.1. Materials

1. High-purity silver rods (99.99%, 1mm diameter)

2. Distilled water (200 ml, pH 7)

3. DC power supply (adjustable, 12-20 V)

2.2. Experimental Setup

2.2.1 Electrodes Preparation:

Two high-purity silver rods were cleaned thoroughly with ethanol and deionized water to remove any surface contaminants. The rods were then dried.

2.2.2 Electrolyte Solution:

Distilled water was used as the electrolyte medium. The pH of the water was measured and adjusted to 7 using a pH meter to ensure a neutral environment for the synthesis.

2.2.3. Electrochemical Cell Configuration:

The cleaned silver rods were immersed in 200 ml of distilled water, ensuring that the rods did not touch each other. The electrodes were connected to a DC power supply set at a voltage range between 12 to 20 V, depending on the specific experimental requirements.

2.2.4. Electrochemical Synthesis

2.3. Initial Parameters:

The synthesis was conducted at room temperature (30°C) to maintain consistent experimental conditions.

2.4. Voltage Application:

The DC power supply was activated, and a voltage of 12-20 V was applied across the silver rods for one hour. This step facilitated the oxidation and reduction processes necessary for the formation of silver nanoparticles.

2.5. Stirring Conditions:

To investigate the effect of stirring time on nanoparticle formation, two sets of experiments were conducted:

- Set 1: Stirring time of 30 minutes.

- Set 2: Stirring time of one hour.

Magnetic stirring was used to ensure uniform mixing of the solution during the electrolysis process.

2.6. Characterization of Silver Nanoparticles

1. UV-Visible Spectrophotometry:

The synthesized Ag-NPs colloid solutions were analyzed using a UV-Visible spectrophotometer (model: XYZ). The absorption spectra were recorded over a wavelength range of 300-600 nm. The characteristic plasmon resonance peak for silver nanoparticles was identified around 390-400 nm, confirming the presence of Ag-NPs.

2. Sample Preparation for SEM:

A few drops of the Ag-NPs colloid solution were deposited onto a clean, conductive silicon wafer. The samples were then gently dried on a heating plate to remove any residual water without disturbing the nanoparticles.

3. Scanning Electron Microscopy (SEM):

The dried samples were analyzed using a scanning electron microscope (model: ABC). SEM images were captured to determine the morphology and size distribution of the Ag-NPs. Multiple images were taken to ensure statistical relevance and accuracy in size determination.

2.7.Data Analysis

1. UV-Visible Spectra:

The absorption spectra were analyzed to determine the wavelength corresponding to the maximum absorbance, indicative of the size and distribution of the nanoparticles.

2. SEM Image Analysis:

The SEM images were processed using image analysis software to measure the size of the nanoparticles. The size distribution was plotted to compare the effects of different stirring times.

3. Results

3.1 UV-Visible Spectra of Silver Nanoparticles

The UV-Visible spectrophotometric analysis provided crucial insights into the optical properties of the synthesized silver nanoparticles. The following observations were made:

3.2. Absorption Peaks:

The UV-Visible spectra of the Ag-NPs colloid solutions exhibited characteristic absorption peaks around 390-400 nm as shown Figure -1, indicative of the surface plasmon resonance (SPR) of silver nanoparticles. This confirmed the successful synthesis of Ag-NPs.

3.3. Effect of Stirring Time:

30-Minute Stirring: The absorption spectra showed a pronounced peak at approximately 395 nm as shown Figure-1, suggesting a relatively broad size distribution of nanoparticles

1-Hour Stirring: The absorption peak was sharper and more defined at around 400 nm shown as Figure-1 , indicating a narrower size distribution and more uniform particle size.

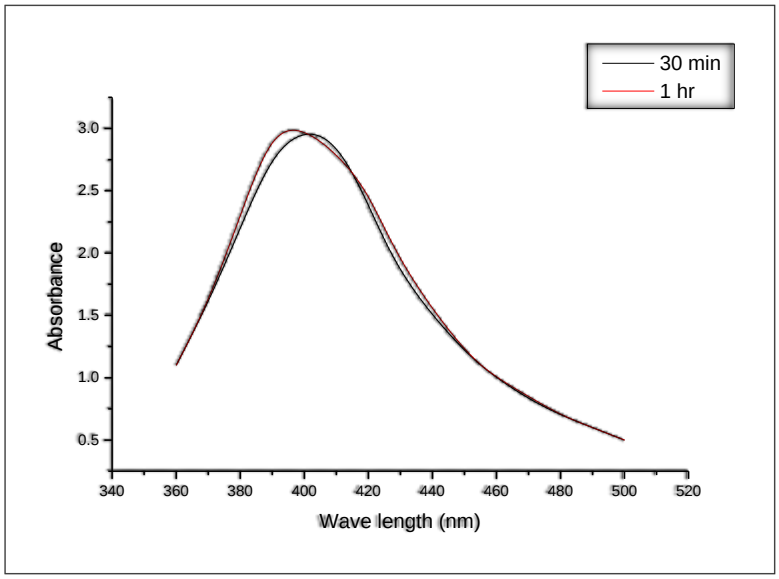

Fig. 1. The UV-VIS absorption spectra of Ag nano colloidal. with different stirring time (30min and 1hr)

3.4. SEM Analysis of Silver Nanoparticles

The morphological and size distribution analysis of the Ag-NPs was conducted using Scanning Electron Microscopy (SEM). The key findings are as follows:

1. Nanoparticle Morphology:

The SEM images revealed spherical silver nanoparticles with relatively smooth surfaces. No significant agglomeration was observed, indicating that the nanoparticles were well-dispersed in the solution.

2.Size Distribution:

30-Minute Stirring: The nanoparticles synthesized with a 30-minute stirring time exhibited a broader size distribution, with particle sizes ranging from 40 to 60 nm. The average particle size was approximately 50 nm show fig-2.

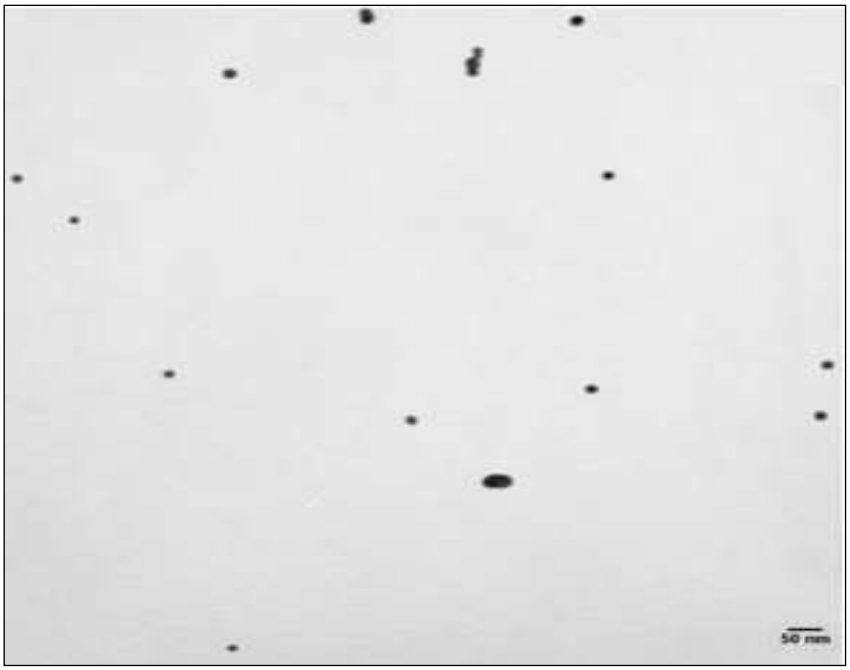

Fig. 2. The SEM image of the silver nanoparticles sample1 stirring time (30 min).

1-Hour Stirring: In contrast, the nanoparticles synthesized with a 1-hour stirring time showed a narrower size distribution, with particle sizes ranging from 30 to 50 nm. The average particle size was approximately 40 nm show fig-3.

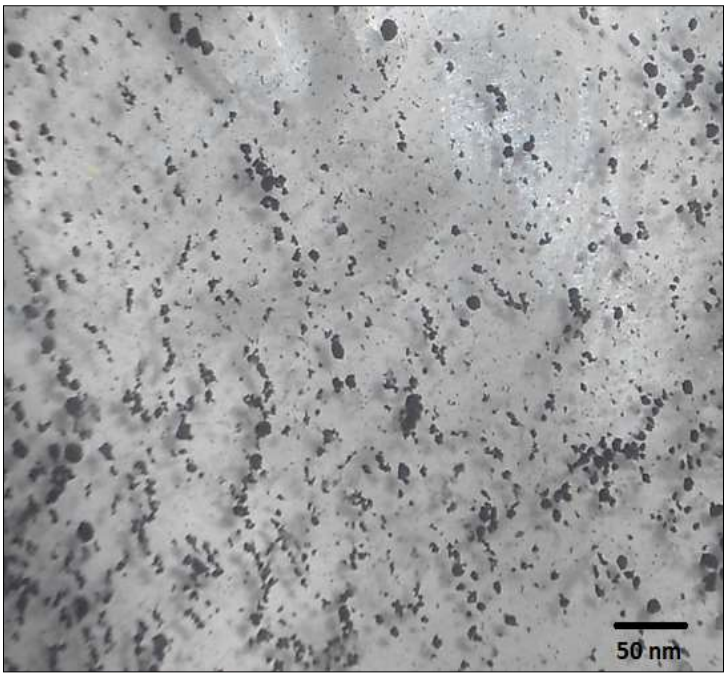

Fig. 3. The SEM image of the silver nanoparticles sample2 stirring time (1 hr).

3.5. Particle Stability:

The SEM images taken over several months showed that the silver nanoparticles remained stable in the colloidal solution without significant changes in size or morphology, demonstrating the robustness of the synthesis method.

3.6. Comparative Analysis

A comparative analysis of the data obtained from UV-Visible spectrophotometry and SEM provided a comprehensive understanding of the impact of stirring time on the synthesis of silver nanoparticles:

1. Uniformity and Size Control:

The results clearly indicate that increasing the stirring time from 30 minutes to 1 hour results in a more uniform and controlled nanoparticle size distribution. The sharper and more defined SPR peak in the UV-Visible spectra for the 1-hour stirring time supports this conclusion.

2.Implications for Applications:

The uniformity in size and stability of the nanoparticles synthesized with longer stirring times make them more suitable for applications that require consistent nanoparticle properties, such as in medical devices, coatings, and antimicrobial treatments.

4.Discussion

The synthesis and characterization of silver nanoparticles (Ag-NPs) were successfully conducted using an electrochemical method, with a specific focus on understanding the effect of stirring time on nanoparticle formation. The results indicate several key findings that have significant implications for the controlled synthesis of Ag-NPs.

4.1. Influence of Stirring Time on Nanoparticle Size and Distribution

4.1.1. UV-Visible Spectroscopy Insights:

The UV-Visible spectroscopy results revealed distinct surface plasmon resonance (SPR) peaks at around 390-400 nm, confirming the presence of silver nanoparticles. Notably, the sharper and more defined absorption peak observed with the 1-hour stirring time suggests a narrower size distribution and more uniform nanoparticle size. This finding aligns with previous studies that highlight the critical role of uniform mixing in achieving consistent nanoparticle characteristics (Kharissova et al., 2013; Lei and Yang, 2007).

4.1.2.SEM Analysis Findings:

The SEM analysis provided detailed visual evidence of the morphology and size distribution of the synthesized nanoparticles. Nanoparticles synthesized with a 1-hour stirring time demonstrated a more uniform and smaller size distribution (30-50 nm) compared to those synthesized with a 30-minute stirring time (40-60 nm). This observation is consistent with the hypothesis that prolonged stirring enhances the homogeneity of the solution, thereby promoting more controlled nucleation and growth of nanoparticles.

4.1.3. Uniformity and Particle Size Control:

The findings demonstrate that longer stirring times result in more uniform nanoparticle sizes, which is advantageous for applications requiring precise particle characteristics, such as in biomedical and antimicrobial applications. Uniform nanoparticles are known to exhibit more predictable interactions with biological systems, enhancing their efficacy and safety in medical treatments (Zhao and Stevens, 1998; Blandón et al., 2012).

4.1.4. Scalability and Economic Viability:

The electrochemical method's simplicity and cost-effectiveness make it a viable option for large-scale production of silver nanoparticles. The ability to control particle size through relatively simple adjustments in stirring time adds to the method's scalability and practicality for industrial applications.

5. Conclusion

This study demonstrates that stirring time is a critical factor in the electrochemical synthesis of silver nanoparticles, significantly influencing their size and uniformity. The findings contribute to the broader understanding of nanoparticle synthesis and provide a foundation for optimizing production methods for various industrial and biomedical applications. The robustness, simplicity, and cost-effectiveness of the electrochemical method, combined with the ability to produce stable and uniform nanoparticles, underscore its potential for large-scale implementation.

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