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STATISTICAL COMPARISON OF SILVER NANOPARTICLE PROPPERTIES SYNTHESIZED WITH TANNIC ACID AND ASCORBIC ACID

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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STATISTICAL COMPARISON OF SILVER NANOPARTICLE PROPPERTIES SYNTHESIZED WITH TANNIC ACID AND ASCORBIC ACID

By Awaleh Daher WABERI

August 2023

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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ABSTRACT

STATISTICAL COMPARISON OF SILVER NANOPARTICLE PROPPERTIES SYNTHESIZED WITH TANNIC ACID AND ASCORBIC ACID

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Silver nanoparticles have been one of the most studied nanomaterials in recent years due to their antibacterial properties and important mechanical properties. Reducing agents have an important place in the synthesis of silver nanoparticles. Although hydrazine and sodium borohydride are among the most preferred reducers, they are not preferred because they are both carcinogenic and toxic. Recently, green reducers have been preferred to toxic chemicals such as sodium borohydride, especially in the reduction step. In particular, the success of glucose and ascorbic acid in the synthesis of nano-sized silver nanoparticles is promising for a more environmentally friendly approach. In this study, in contrast to literature studies, the properties and efficacy of silver nanoparticles obtained with tannic acid and ascorbic acid, in particular particle size distribution, will be statistically compared. This study proposed a systematically design of expert method for the synthesis of silver nanoparticle (AgNPs) and characterized with the use of Taguchi L_4 experimental design. The experiments were carried out using 2^3 orthogonal arrays and main and interaction effects are prepared. Silver nitrate is used as a raw material and soluble starch as a coating agent. Tannic acid and ascorbic acid will be used as reducing agents. Synthesized nanoparticles will be characterized using FTIR, zetasizer and ultraviolet-visible (UV-Vis) spectroscopy. The average size distribution of silver nanoparticles and product efficiency will be statistically compared by paired-t analysis and statistical comparison of the properties of silver nanoparticles obtained with tannic acid and ascorbic acid. The glucose/$AgNO_3$ and ascorbic/$AgNO_3$ molar ratios were shown to have the greatest influence on AgNPs particle size dispersion. The findings demonstrate that the lowest variances AgNPs are produced at the greatest Ascorbic/$AgNO_3$ molar ratios. As a result, it can be said that the higher-quality AgNPs production process is possible by adjusting Ascorbic/$AgNO_3$ molar ratio.

2023, 46 pages

Keywords: Ascorbic acid, Tannic acid, Silver nanoparticles, Statistics

ÖZET

TANNİK ASİT VE ASKORBİK ASİT İLE SENTEZLENEN GÜMÜŞ NANOPARÇACIK ÖZELLİKLERİNİN İSTATİSTİKİ KIYASLASNMASI

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Ağustos 2023

Gümüş Nanoparçacıklar, malzemelere gerek anti bakteriyel özellik sağlaması gerekse önemli mekanik özellikler kazandırması nedeniyle son yıllarda oldukça üzerinde çalışan nano malzemelerden biri olmuştur. Gümüş nanoparçacıkların sentezlenmesinde indirgen ajanlar önemli bir yer tutmaktadır. Hidrazin ve sodyum bor hidrür en çok tercih edilen indirgenler arasında yer alsa da gerek kanserojen olması gerekse toksik olması nedeniyle tercih edilmemektedir. Son zamanlarda özellikle indirgeme aşamasında sodyum bor hidrür gibi toksik kimyasallar yerine yeşil indirgenler tercih edilir olmuştur. Özellikle glikoz ve askorbik asidin düşük nano boyutta gümüş nanoparçacık sentezindeki başarısı daha çevreci bir yaklaşım için umut vaat etmiştir. Bu çalışmada literatürdeki çalışmalardan farklı olarak tannik asit ve askorbik asit ile elde edilen gümüş nanoparçacıkların başta parçacık boyutu dağılımı olmak üzere özellikleri ve verimliliği istatistiki olarak kıyaslanacaktır. Bu çalışma, gümüş nano partikülün (AgNPs) sentezi için sistematik bir deney tasarımı yöntemi önermiştir ve kalite kriterleri Taguchi L_4 ortogonal dizinlerin kullanılması ile karakterize edildi. Deneyler 2^3 ortogonal dizin kullanılarak gerçekleştirilmiş ve ana ve etkileşim etkileri hazırlanmıştır. Kaynak malzeme olarak gümüş nitrat kaplama ajanı olarak çözülebilir nişasta kullanılacaktır. Tannik asit ve askorbik asit ise indirgeyici etmen olarak kullanılacaktır. Sentezlenen nanoparçacıkların karakterizasyonu Zetasizer ve Ultraviyole-Görünür Spektroskopi (UV-Vis) cihazları ile gerçekleştirilecektir. Veri çifti analizi ile gümüş nanoparçacıkların ortalama parçacık boyutu dağılımı ve ürün verimliliği istatistiki olarak kıyaslanacaktır. Tannik asit ve askorbik asit ile elde edilen gümüş nanoparçacıkların özelliklerini istatistiki olarak kıyaslanması sağlanmıştır. Glikoz/$AgNO_3$ ve askorbik/$AgNO_3$ molar oranlarının, AgNP'lerin parçacık boyutu dağılımı üzerinde en büyük etkiye sahip olduğu gösterilmiştir. Bulgular, en düşük varyanslı AgNP'lerin en büyük askorbik/$AgNO_3$ molar oranlarında üretildiğini göstermektedir. Sonuç olarak askorbik/$AgNO_3$ molar oranının ayarlanması ile daha kaliteli AgNP üretim sürecinin mümkün olduğu söylenebilir.

2023, 46 sayfa

Anahtar Kelimeler: Askorbik asit, Tannik asit, Gümüş nanoparçacıklar, İstatistik

PREFACE AND ACKNOWLEDGEMENTS

I'm relieved to have finished this thesis after a year of arduous effort. It was a remarkable event that I will cherish for a very long time.

I would like to express my gratitude in the sincerest possible way to my supervisor, Assoc. Prof. Dr. Barış ŞİMŞEK and my co-advisor Assoc. Prof. Dr. Ömer Faruk DİLMAÇ, for their patience, advice and support. You have always taken the greatest interest in my work, with dynamism and competence.

I would also like to thank Dr. Mücahit UĞUR for his support during the experimental studies. I was able to appreciate your great human qualities, which contributed significantly to the completion of my work. As a token of my deep gratitude, please find herewith the expression of my most sincere appreciation.

I would like to express my infinite thanks to my family, who have always supported and encouraged me throughout my life. I am particularly grateful for their support, motivation, and encouragement to achieve my goals and accomplishments.

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Awaleh Daher WABERI
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CONTENTS

LIST OF SYMBOLS

$C_6H_8O_6$	Ascorbic acid
°C	Celsius degre
cm	Centimetre
$C_6H_{12}O_6$	Glucose
K	Kelvin
µm	Micrometre
µS	Microsiemens
mV	Millivolt
nm	Nanometer
ppm	Parts per million
pH	Potential of hydrogen
S/N	Signal to noise ratio
Ag	Silver
AgNPs	Silver nanoparticles
$AgNO_3$	Silver nitrate
N_aOH	Sodium hydroxide
$(C_6H_{10}O_5)_n$	Starch
$C_{76}H_{52}O_{46}$	Tannic acid
H_2O	Water
W	Watts

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AA	Ascorbic acid
AB	Absorbance
DOE	Design of experiments
DLS	Dynamic light scattering
DS	Drug substance
EC	Electrical conductivity
Mob	Mobility
NP	Nanoparticle
RA	Reducing agent
SEM	Scanning electron microscopy
SPR	Surface plasmon resonance
S/L	Solid and liquid
TA	Tannic acid
TC	Thermal conductivity
TGA	Thermogravimetric analysis
TEM	Transmission electron microscopy
UV-Vis	Ultraviolet-visible spectroscopy
XRD	X-Ray diffraction

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1. INTRODUCTION

1.1 Literature Review

Nanotechnology is a multidisciplinary branch of science that has grabbed the interest of scientists and engineers worldwide. Nanotechnology enables the simple manufacture of biocompatible metal-based nanoparticles that have a broad variety of potential uses in the medical and biological sciences (Kakakhel *et al.* 2021). Nanomaterials have grown increasingly helpful for important applications such as biochemistry, pharmaceutical analysis, health monitoring, scientific diagnostics, monitoring the environment, and ensuring food safety during the last decade (Sharma *et al.* 2021). As a result, nanotechnology is the study of materials with dimensions between 1 and 100 nm (He *et al.* 2019).

Nanomaterials have a wide range of applications owing to their unique characteristics. Depending on their essential structures, nanoparticles might be formed of metals or nonmetals. The primary components of metal nanoparticles include gold, silver, copper, magnetic elements (cobalt, nickel), and semi-conductors (Ramya *et al.* 2022).

Silver nanoparticles (AgNPs) are among the most extensively employed nanomaterials in the area of nanotechnology and one of the most commercialized nanoscale materials is nano-silver (Reidy *et al.* 2013). Silver exhibits physicochemical features such as conductivity, chemical stability, and catalytic and antibacterial activity (Rudrappa *et al.* 2022).

Applied research has greatly benefited from the use of AgNPs, which are very small particles. AgNPs exhibit distinctive optical features due to collective electron oscillations in response to incoming light (Jouyban and Rahimpour 2020).

Various industrial uses employ silver nanoparticles, textiles (clothing and bedding), including food (additives, food packaging, refrigerator linings), and cosmetics and hygiene goods (toothbrushes, hair straighteners, disinfectant sprays, etc.). They are used primarily for their antimicrobial and antifungal activities. It is used in a variety of industrial applications, including AgNPs and their colloidal forms have been studied for their antibacterial and catalytic activity, their high conductivity, and their chemical stability. Silver nanoparticles have many applications in a wide variety of fields such as optics, electronics, magnetics, catalysis, and medicine, as shown in the following Figure 1.1 (He *et al.* 2019).

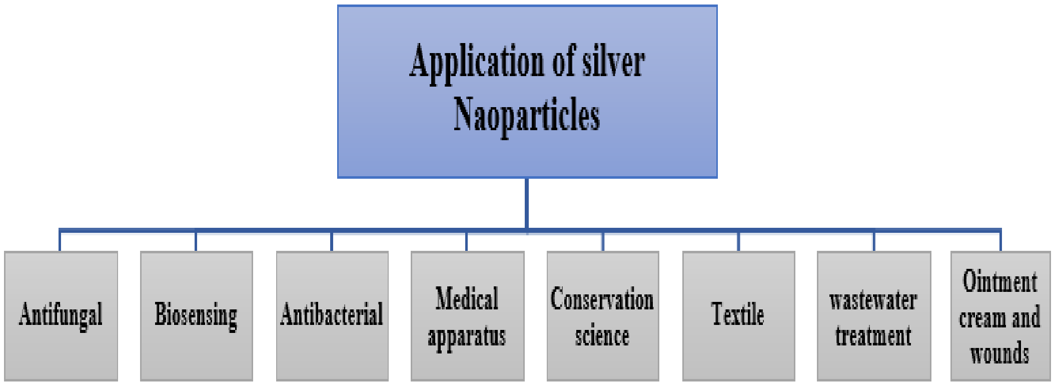

Figure 1.1 Applications of AgNPs in various fields (He *et al.* 2019)

For the production of AgNPs, several methods, including a chemical method, have been investigated in the past (Barveen *et al.* 2021), a plant-mediated approach (Girilal *et al.* 2015), and a microbiological approach (Ahmed *et al.* 2021). It was discovered that chemically produced silver nanoparticles (sodium borohydride and sodium citrate) are more harmful to mesenchymal stem cells (derived from mouse bone marrow) than green generated silver nanoparticles, similarly (Kummara *et al.* 2016) concluded that green produced silver nanoparticles displayed preferential cytotoxicity towards cancer cells (NCI-H460) relative to normal cells.

Due to its wide range of applications in adsorption, chemistry, water management, optical sensors, and drug delivery, the green synthesis of silver nanoparticles (AgNPs) has developed become one of the most promising topics for future medicinal research

(Femi-Adepoju *et al.* 2019, Some *et al.* 2019), also a technique that is becoming more popular for creating nanoparticles with sizes between 1 to 100 nm (Al Mashud *et al.* 2022).

The biological extract of AgNPs undergoes a green synthesis that transforms silver salts (Ag^{+}) to metallic silver (Ag^{0}). Biological molecules may serve as both reducing agents and metal salt reducers. (Roy *et al.* 2019). Biosynthesized AgNPs are biocompatible, stable, highly soluble, and provide a high yield without aggregating. Consequently, the biological synthesis of nanomaterials is straightforward, nontoxic, and more ecologically friendly than chemical synthesis, which is expensive and dangerous to living creatures (Joshi *et al.* 2022).

Top-down and bottom-up approaches are the two most used nanoparticle synthesis techniques. Top-down procedures include the use of physical tools to cut, grind, and shape materials. Bottom-up procedures, on the other hand, are chemical or biological mechanisms that are regarded the best for creating nanoparticles, where atoms or molecules self-assemble into bigger particles, as seen in Figure 1.2 displays a number of recent research that generated AgNPs using various techniques (Sharma *et al.* 2021).

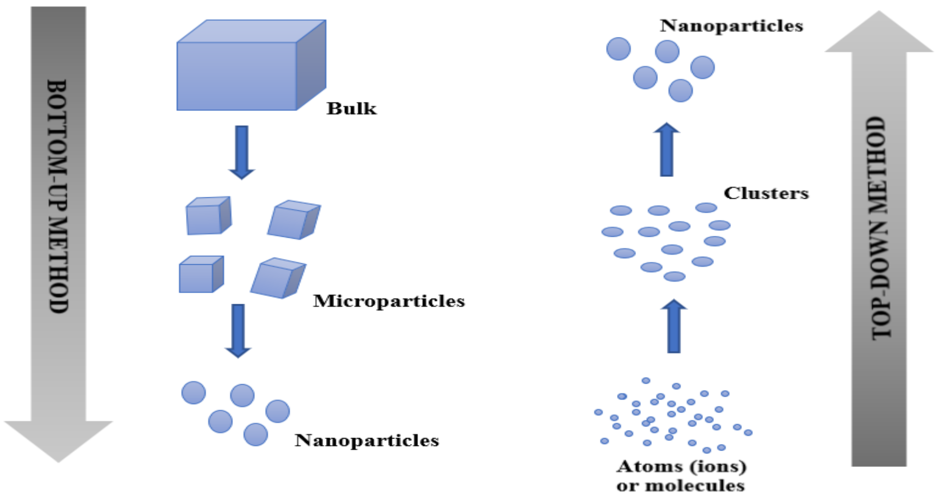

Figure 1.2 Top-down and bottom-up approaches to nanomaterials (Sharma *et al.* 2021)

After the synthesis of nanoparticles is done, it is important to evaluate their stability, size, and toxicity and optimize their properties for a specific application. Therefore, the characterization and optimization of nanoparticles are essential to understanding their physicochemical and biological properties. There are different methods to characterize or optimize the obtained nanoparticles.

The Taguchi method is a statistical method for enhancing a product's or process' production specifications. By adjusting variables like temperature, reagent concentration, and reaction time, it is possible to maximize the production of silver nanoparticles. In a study done in 2021, Taguchi's approach was utilized to perfect the synthesis of silver nanoparticles made from plant extracts, yielding small, evenly formed nanoparticles (Chakravarty *et al.* 2023). ANOVA is another useful statistical technique for the optimization and characterization of silver nanoparticles (Azmy *et al.* 2022). It allows one to determine the relative importance of each synthesis parameter on the size, shape, and size distribution of the nanoparticles (Rosca *et al.* 2022). SEM also known as scanning electron microscopy, is a technique for imaging that allows visualization of the shape and size of silver nanoparticles. A study in 2021 used SEM to characterize silver nanoparticles synthesized using a plant extract, showing that the nanoparticles were spherical with an average size of 45 nm (Basak *et al.* 2022).

UV-Vis spectroscopy is a commonly used technique for the characterization of silver nanoparticles (Maleš *et al.* 2022). It measures the absorption of light by nanoparticles as a function of wavelength and determines the size, shape, and size distribution of the nanoparticles. A 2020 study used UV-Vis spectroscopy to characterize silver nanoparticles synthesized using a plant extract, showing maximum absorption at 422 nm and an average size of 33.2 nm (Hannachi *et al.* 2023). Finally, a Zetasizer is a method for measuring the charge and size of silver nanoparticles in solution. It can also be used to assess a nanoparticle's stability in various solution environments. The Zetasizer was utilized in a study in 2021 to evaluate silver nanoparticles made from a plant extract. These particles had an average size of 35 nm and a negative zeta charge of-11.9 mV (Qadri *et al.* 2022).

Zamarchi *et al.* (2021), claim that the manufacture of nanoparticles from a plant extract is effective, quick, easy, and environmentally friendly. The stabilization time of the extract, the temperature, the extract/water ratio, and finally the concentration of silver nitrate were significant factors that they took into consideration during the study a reducing and stabilizing substance that was made from an extract of pine nuts (Araucaria angustifoliata). A good result in repeatability from electrode to electrode (relative standard deviation) under optimum conditions, with a detection limit of 8.10*10-5 mol/L^{-1}, was shown in the analysis of the parameters impacting the performance of the sensor in order to optimize the synthesis of AgNPs.

According to Karhan *et al.* (2017), AgNPs may be employed as an adhesive for specific electronic devices or as conductive inks based on their unique electrical and optical capabilities. It has been reported that in order to reach the required silver nanoparticle size, a desirability function technique based on a surface methodology was initially used in conjunction with the green synthesis process, resulting in an average size improvement of 7.9%. After analyzing the data, it was determined that the standard deviation was 89.3 percent less than in the prior research. The findings of the conducted investigation indicate that the production variation of AgNPs must be minimized to achieve a high-quality, large-scale manufacturing process.

Ponsanti *et al.* (2020), manufactured NP flower-shaped Ags with a green approach involving sago starch (Sa-S), cassava starch (Ca-S), and corn starch (AgFL). In the investigation by Khan et al., starch served as a reducing agent. In the production of AgNPs, glucose was present in the starch, which allowed the Ag ions of silver nitrate to be reduced into NP Ags. TEM, XRD, UV-Vis, FTIR and thermogravimetry have been utilized in this study and for the characterization of AgNPs (TGA). According to the TEM pictures, the floral shapes were detected, and the nanoparticle dispersion was 47.8 nm for corn starch, 107.5 nm for cassava starch (Ca-S), and 118.5 nm for sago starch (Sa-S). The X-ray diffraction pattern confirmed the center-oriented cubic structure (Fcc), and UV-VIS analysis found that silver nanoparticles absorb most strongly between 420 and 430 nm. Discovered that the AgNPs created with the various starches were flower shaped. Additionally, the flower-shaped silver nanoparticles made from corn starch were smaller than those made from cassava and sago starches.

In the investigation done by (Dubas and Pimpan 2008), the synthesized peptides were initially produced without the use of reagents. In a calorimetric test designed to detect ammonia in solution, only ultraviolet light was utilized. In the presence of poly (methyl acid), AgNPs are produced by exposing a silver nitrate solution to a low-power UV light, it acts as both a reducing and capping agent PMA.

In addition, UV-Vis spectroscopy has been used to monitor the shift in location and amplitude of the localized plasmon resonance band (SPR) of the Page. The generation of spherical particles with an average particle size of 8 nm was confirmed by transmission electron microscopy (Dubas *et al.* 2008). It is proven that the Pages solution changed color from purple to yellow when combined with ammonia concentrations ranging from 1 to 100 ppm. This technique of producing NP may be used as a calorimetric test to determine whether or not ammonia has been added to water.

Kanniah *et al.* (2021), generated AgNPs utilizing P. nigrum grain extract as an effective, simple reducing agent and silver-based chitosan nanocomposite (Ag/CS NC) in their investigation. AgNPs were studied by UV-Vis, XRD, SEM, TEM and FTIR. Indicative of the creation of silver nanoparticles was the development of a surface plasmon resonance peak (SPR) at around 430 nm. The bulk of the silver nanoparticles obtained were spherical and varied in size from 15 to 38 nm, as determined by TEM examination.

To determine the phytochemical contents of the P. nigrum grain extract, a liquid chromatographic and spectroscopic study was conducted. The AgNPs exhibited strong cytotoxic activity against the dangerous human cancer cell lines PANC-1, SKOV-3, PC-3, MDA, MB-231, and Hela. The presence of silver in the suspension was seen in the TEM image’s brilliant spots.

Restrepo *et al.* (2021), in their conducted study, Controlling the shape and size of AgNPs is essential for enhancing their antibacterial, chemical, and physical characteristics. It has been said that the use of the various capping agents makes it possible not only to control the stability over time of the nanostructure but also the particle size, the agglomeration, and the morphology of the material. This interaction of the capping agent with the nanoparticles' surface influences the resulting nanostructure.

Mavani *et al.* (2013), indicates that the antibacterial activity of AgNPs is improved owing to their physical, visual, and chemical attraction to other particles. Researchers have shown that the optical characteristics of AgNPs are highly dependent on the nanoparticles' diameter and diffraction index. It has been discovered that AgNPs effectively diffuse and absorb light owing to their optical characteristics. Manufacture these particles using the chemical reduction approach of Agno and Nash4. The addition of PVP inhibited particle aggregation, and borohydride anions were taken up by the AgNPs. Has a surface plasmon resonance (SPR) at 386 nanometers. For solutions of AgNPs, the spectrophotometer exhibits a yellow hue and an estimated diameter of 10 to 20 nm.

In the work done by Mahendran *et al.* (2022), silver nanoparticles were generated by evaluating antibacterial activity and aqueous extracts of the leaves. The existence of synthesized nanoparticles was verified by (XRD), (UV-Vis), (SEM), and (FT-IR). At 450 nm, the surface plasmon resonance causes a considerable absorption. The investigation (XRD) indicated an average crystal size of 35 nm, confirming the crystalline structure of the substance. Additionally, FTIR was used to estimate the potential bioreduction involved in the bioreduction of silver ions. Antimicrobial activity has enabled confirmation of gram-positive and gram-negative bacterial effectiveness.

Using soluble starch as a reducing agent and stabilizing agent, Vigneshwaran *et al.* (2006), were able to synthesize AgNPs that were stable at 25 degrees Celsius for three months in their investigation. The nanoparticles were stable in aqueous solution, and using electronic micrographs, their size was determined to be between 10 and 34 nm. Excited at 380 nm, X-ray diffraction examination revealed its cubic center-face structure (Fcc), and iodometric titration proved its entrapment. Typically, when silver nanoparticles are combined with soluble starch, the emission peak occurs at 553 nm.

Başar *et al.* (2022) described a study that examined the impacts of various parameters on the pyrolysis of blended lignite, pistachio and municipal solid waste. Among the experimental parameters considered are the mass mixture ratio, pyrolysis temperature, pyrolysis time, heating rate, and catalyst amount. Using the Taguchi method and ANOVA analysis, the impact of these parameters on char, liquid, and gas efficiency was statistically evaluated. According to the research findings, the quantity of catalyst is the most important factor for solid efficiency, while the mass ratio is essential for liquid and gas efficiency. ANOVA analysis and the Taguchi technique were used to confirm the optimal experimental settings for liquid, char, and gas efficiency, respectively. Carbonization was analyzed using FTIR, XRD and SEM techniques to ascertain the structural changes of the solid product at various temperatures. To sum up, this paragraph gives a brief summary of the study's aims, methods, results, and analysis methods.

Ansari *et al.* (2023) discuss the use of diagnostic statistics to identify cases that have a substantial impact on the characteristics of a fitted linear regression model. Textual evidence indicates that a dataset may contain both singularly influential cases and influential multiple case subsets, necessitating the ability to assess the joint influence of cases. The objective of this study is to evaluate Cook's distance measure, a diagnostic instrument for identifying influential multiple case subsets, and to present a method for locating such subsets using this measure. Using a MINITAB Statistical Software macro, the method is applied to two example analyses in this paragraph. Overall, this paragraph provides a concise summary of the purpose, methodology, and application of Cook's distance measure for identifying influential multiple case subsets in a linear regression model. Present the functionalization of cellulose as an innovative strategy for the sustainable utilization of renewable materials and underscore the significance of converting waste biomass into useful materials without producing pollutants. The focus of this investigation is the synthesis of a papermaking strength additive from Pinus roxburghii sarg needles. The synthesis is performed via an etherification reaction, and

Taguchi's L25 orthogonal incomplete array is utilized to optimize the reaction conditions in order to achieve a higher degree of substitution (DS). Using the signal-to-noise ratio (SNR) method, the method's efficacy is evaluated, and a maximum DS value of 2.67 is attained under optimized reaction conditions. The analytical methods used to confirm the functionalization of pine needle alpha-cellulose (PNAC) to PNCEC are also described in this paragraph. These methods include: Fourier transform infrared spectroscopy, proton nuclear magnetic resonance, X-ray diffraction, differential scanning calorimetry, thermogravimetric analysis, and scanning electron microscopy. By measuring the tear index, tensile index, and explosion index of laboratory handsheets, it was determined that PNCEC can increase the physical strength of paper by up to 25.5%. The paragraph provides a clear and concise summary of the objectives, methodology, results, and implications of the study.

Rashed *et al.* (2022), describe a study that seeks to improve production yield by optimizing the crushing parameters of aggregates using Taguchi methods. The paragraph provides a straightforward and concise summary of the study's experimental design and methodology. In a cone crusher, the most important parameters, such as feed rate, eccentric speed, closed side setting, and throw, are explicitly defined. The Taguchi Design of Experiment (DOE) method and the L09 orthogonal array are used to evaluate the process parameters, while the ANOVA technique is employed to identify the parameters that have a significant impact on the objective function. Also mentioned is the use of the signal-to-noise ratio for optimization. The results indicate that the closed-side configuration has the greatest impact on production yield, while eccentric speed, throw, and feed rate of rock aggregates have negligible effects. Overall, the paragraph provides a clear and concise summary of the objectives, methodology, and main findings of the study.

1.2 The Aim of the Thesis

Silver nanoparticles have been one of the most studied nanomaterials in recent years due to their antibacterial properties and important mechanical properties.

The synthesis of silver nanoparticles with green synthesis, as green reductants have been preferred to toxic chemicals such as boron and sodium hydride, especially in the reduction step. Tannic acid and ascorbic acid were chosen as green reducing agents, and glucose was chosen as a capping agent for environmental friendliness.

A comparison of the average particle size distribution of silver nanoparticles and the effectiveness of the product is made statistically by a data pair analysis.

Using UV-Vis, FTIR and Zetasizer spectrum analyses, we analyzed the influence of concentration, pH, extract content, and metal ions on AgNPs creation and compared the size stability of the synthesized AgNPs to choose the most stable.

- Statistically compare the properties of silver nanoparticles obtained with tannic acid and ascorbic acid.
- Determine the effect of tannic acid and ascorbic acid on the properties of silver nanoparticles.

2. MATERIALS AND METHODS

2.1 Materials

- Silver nitrate
- Ascorbic acid: reducing agents.
- Tannic acid: reducing agents.
- Starch: coating agent.
- Glucose
- UV-Vis spectrophotometry:
  - For characterizing the synthesized AgNPs.
- Zeta-sizer:
  - For measure the size and distribution of AgNPs particles.
- FTIR:
  - To study material properties as a function of infrared light absorption).
- Flux calorimeter:
  - To measure the thermal conductivity of the AgNPs solution.
- Electrical conductivity meter:
  - To measure the electrical conductivity of the AgNPs solution.
- MINITAB

2.2 Methods

2.2.1 Synthesis method of silver nanoparticles

To synthesize silver nanoparticles there are generally 3 methods: the chemical, physical and biological method:

Physical methods

The most prevalent physical processes for preparing nanoparticles are laser ablation and evaporation-condensation. These physical processes make it possible to create AgNPs using a modest ceramic heater (Figure 2.1) (Al-Radadi and Abu-Dief 2022). Laser ablation is a process in which a laser beam is used to vaporize a target material, creating a plasma plume. The high-energy plasma plume rapidly cools, forming nanoparticles of the target material. The size and shape of the nanoparticles can be controlled by adjusting the laser parameters such as laser power, pulse duration, and focus. The nanoparticles formed can be collected using a variety of methods such as inert gas condensation, centrifugation, or electrostatic precipitation.

However, these methods have substantial limitations, such as solvent contamination, uneven distribution, low energy efficiency and high-power usage (Balachandran *et al.* 2022).

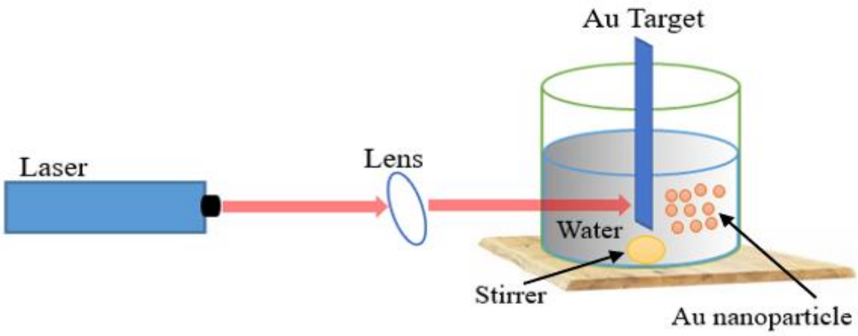

Figure 2. 1 Laser ablation (Al-Radadi *et al.* 2022)

Chemical methods

In chemical reduction, which utilizes both organic and inorganic reducing agents, is the most prevalent method for generating AgNPs. Several reducing chemicals, including sodium citrate, sodium borohydride, ascorbate, and hydrogen, may assist in the reduction of silver ions to metallic silver and the consequent formation of silver nanoparticles (Thayyil *et al.* 2021).

In comparison to their physical equivalents, chemical techniques have the benefit of producing nanoparticles at a high rate. Chemical technologies offer a significant advantage over their physical equivalents due to their ability to produce a large number of nanoparticles (Figure 2.2) (Asimuddin *et al.* 2020).

In addition, the manufacturing of NPs with well-defined dimensions is extremely challenging, and further precautions must be taken to prevent particle aggregation (Qu *et al.* 2016).

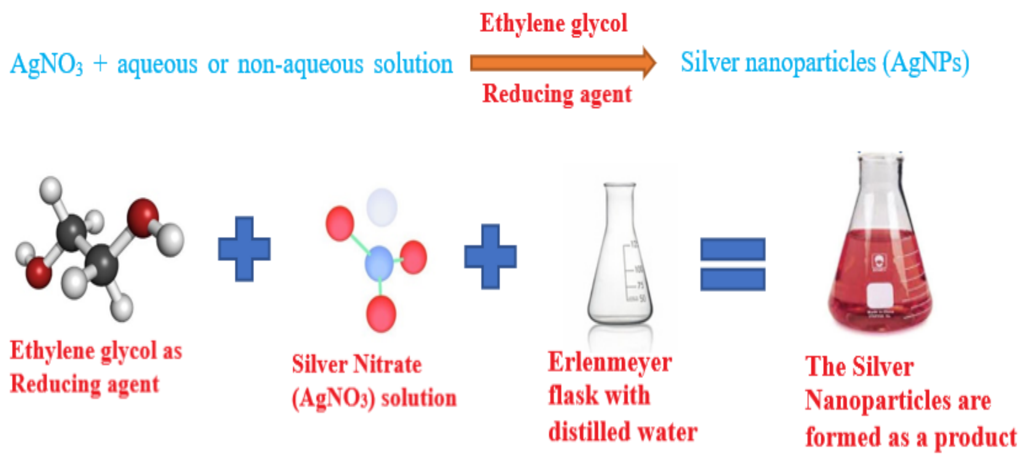

Figure 2. 2 Chemical reduction of silver nanoparticle (Asimuddin *et al.* 2020)

Biological methods

In biological approaches (also called as "green synthesis") use biological agents, plants, or microorganisms to produce AgNPs (Giri *et al.* 2022). Phytoplankton and microorganisms Due to the high potential yields and enormous amounts of protein involved, the microbial production of AgNPs has attracted a great deal of interest (Pallela *et al.* 2018)**.** However, this strategy is connected with challenges in culture development and maintenance.

2.2.2 Synthesis of silver nanoparticles by green synthesis

The term "green synthesis" refers to the production of nanoparticles (NPs) using biological reducing agents and stabilizers found in plants, microbes, or biosurfactants. Reducing agents convert metal ions within the reaction mixture into metal atoms. The metal atoms get stable and form NPs by grouping together. The increased size of the NPs is a result of the prolonged clustering that follows the reduction procedure (Karhan *et al.* 2017).

The majority of these reduction agents are deemed environmentally harmful. Growing awareness of the need for total waste removal, or at least waste reduction, has prompted researchers to investigate alternate synthetic approaches. Recent efforts have been made to find environmentally friendly ways for producing silver nanoparticles (Raveendran *et al.* 2003).

The creation of AgNPs via a green chemistry method must be reviewed in three distinct ways: the selection of a solvent medium, the selection of a non-toxic reductant, and the selection of environmentally friendly materials for the stabilization of silver nanoparticles. Glucose was used as a green reducting agent and water is typically employed as an eco-friendly solvent (Karhan *et al.* 2017).

Created the AgNPs utilizing the tannic acid reduction method. By mixing tannic acid solution with silver nitrate solution at a pH of 8. The silver nitrate's hue changes to yellow as soon as the tannic acid solution is applied. According to their findings, the hydroxyl group linked to the furan ring lost its proton during the adsorption process of ascorbic acid before interacting with Ag^+ ions.

2.2.3 Taguchi method

Taguchi's technique comprises of an experimental design strategy that greatly reduces the number of experiments in a parametric study (Karna *et al.* 2012) compared to factorial experimental design. Recently, these methods have been utilized for parametric analysis and optimization in experimental work and numerical investigations of computational fluid dynamics. The objective function is the outcome of the system's optimization, maximization, or minimization (Chen *et al.* 2022, Moein Darbari *et al.* 2022).

Computing the Taguchi technique involves determining for the signal-to-noise (S/N) ratios for each investigated factor, calculating delta values from the S/N ratios, and identifying the order of each factor (Hasanzadeh *et al.* 2022). Objective functions such as production cost should constantly be minimized, hence the "Smaller is Better" S/N ratio is the most appropriate. For objective purposes such as quality and production yield, the industry's performance should be maximized, hence the "Bigger is Better" S/N ratio is most applicable (Garmim *et al.* 2022). In some instances, such as surface thickness and other product attributes, the process requirements for this type of objective function should be adequate. The optimal nominal S/N ratio should be selected (Gurway *et al.* 2022).

The signal-to-noise S/N ratio is defined in three distinct ways: the larger is better (Equation 2.1), the lower is better (Equation 2.2), and the nominal is best (Equation 2.3) (Bademlioglu *et al.* 2018, Başar *et al.* 2022). The following equations are listed:

The bigger is the better:

$$S/N = -10 \log \left(\sum_{i=1}^{n} \frac{1}{Y_i^2} \right) \tag{2.1}$$

The smaller is the better:

$$S/N = -10 \log \left(\sum_{i=1}^{n} Y_i^2 \right) \tag{2.2}$$

Nominal the best:

$$S/N = 10 \log \left(\frac{\mu^2}{\sigma^2} \right) \qquad (2.3)$$

The process for determining the effectiveness of various parameters, x and μ represent the mean and standard deviation, respectively (Başar *et al.* 2022). The value of the objective function is represented by Yi. The process involves calculating the difference between the highest and lowest signal-to-noise values for each parameter, then ranking the parameters based on the size of these differences (with the parameter having the largest difference being considered the most effective) (Yuce *et al.* 2022).

The Taguchi approach method involves using a type of design known as orthogonal arrays to evaluate all possible parameter combinations, thereby reducing the number of experiments required to solve a problem (Hasanzadeh *et al.* 2022). The selection of the appropriate orthogonal array is determined by the total degree of freedom (OF). The DOF for each component is determined by subtracting one from the number of levels and must be less than the DOF of the orthogonal array being used (Ning *et al.* 2016).

Existing experimental design actions are challenging to organize and implement. In addition, several experimental operations are needed to enhance parameter collecting. In order to circumvent this obstacle, a tactical method known as the Taguchi method with orthogonal network architecture permits the examination of all parameters with a small number of experiments. The work's design involves the following steps (Mutyalu *et al.* 2021):

- Choosing the variables that are not dependent on others.
- Determining multiple levels for each chosen independent variable
- Choosing a specific design called orthogonal arrays.
- Assigning each chosen independent variable to a specific column
- Conducting the experiments
- Examining and interpreting the collected data.

2.2.4 Minitab statistical software

Minitab is a statistical application that simplifies data analysis and identifies the most significant parameters or variables in a variety of experimental data sets (Roos and Stawarczyk 2012). This tool made it possible for us to perform experiments, develop mathematical models, and optimize the variables of chemical. Minitab might assist in achieving optimum outcomes with minimal effort, hence saving time and more economical (Ebrahimi *et al.* 2022).

Minitab is a bundle of statistical software that is frequently used for data analysis and statistical process control. It is widely utilized in numerous sectors, including engineering, science, and business. Minitab offers numerous statistical methods for data analysis, including (Dhanaraj and Rathinasuriyan 2022):

Descriptive numbers (standard deviation, mean, median etc.)

- Regression analysis
- ANOVA (Analysis of Variance)
- Control charts
- Process capability analysis
- Hypothesis testing
- T-tests
- Nonparametric tests
- Statistical process control

Minitab also includes a range of data visualization tools, such as scatter plots, histograms, and box plots, which can help you understand and communicate your data more effectively (Prakash Pasupulla *et al.* 2022). It also has a comprehensive set of statistical formulas and functions that can be used to perform more advanced analyses. In addition to its data analysis capabilities, Minitab also has tools for project and quality management, including capability analysis, Six Sigma tools, and lean tools (Roos *et al.* 2012).

Overall, Minitab is a powerful and versatile statistical software package that is well-suited for a wide range of applications.

2.2.5 Analysis of variance

According to (Kishore *et al.* 2017), analysis of variance (ANOVA), is a statistical approach that enables us to identify the relative relevance of numerous process parameters that impact system performance. ANOVA is a well-known and frequently-utilized statistical technique that facilitates the interpretation of experimental data by computing the contribution ratio of each variable (Yuce *et al.* 2022). The purpose of ANOVA is to group a set of experimental data based on a shared variable or parameter and a response or objective function (Chen *et al.* 2022). Each CFD problem-solving parameter's relevance is determined using ANOVA.

The ANOVA computation steps are as follows (Equation 2.4, Equation 2.5 and Equation 2.6):

$$SS_T = \sum_{i=1}^{N} (Y_i - \bar{Y})^2 \quad (2.4)$$

$$\bar{Y} = \frac{1}{N} \sum_{i=1}^{N} (Y_i) \quad (2.5)$$

$$SS_P = \sum_{j=i}^{t} \frac{(SY_j)^2}{t} - \frac{1}{N} \left[\sum_{i=1}^{N} Y_i \right]^2 \quad (2.6)$$

The process of determining the sum of squared errors (SSJ) between a series of N experiments and the numerical or experimental result of the ith experiment (Yi) (Doran *et al.* 2015). SSJ consists of the sum of squared errors (Sse) and the sum of squared deviations (SSP) attributable to each process parameter. P is one of the parameters, j is the number of levels for parameter P, and t is how many times each level of parameter P is repeated (Yuce *et al.* 2022).

In statistical hypothesis testing, the p-value is used to quantify the likelihood of observing an extreme outcome if the null hypothesis is true. In other words, the p-value allows you to decide if your experiment’s outcomes are due to chance or statistically significant (Patil *et al.* 2022).

The p-value is utilized in ANOVA (Analysis of Variance) to test the null hypothesis that the means of two or more groups are equal. ANOVA is a statistical test that is used to examine whether or not the means of two or more groups differ significantly. You are allowed to reject the null hypothesis and draw the conclusion that there is a statistically significant difference between the means of the groups if the p-value is lower than the significance threshold that you have specified (which is normally 0.05) (Başar *et al.* 2022).

2.3 Methodology

2.3.1 Synthesis of silver nanoparticles using tannic acid and ascorbic acid

The objective of our study is to statistically compare the properties of the silver nanoparticles obtained with tannic acid and ascorbic acid. And determine the effect of tannic acid and ascorbic acid on the properties of silver nanoparticles.

According to Karhan *et al.* (2017), there are five flow processes to choose the ideal mixing ratios for the AgNPs production process in order to optimize silver nanoparticles. First, the quality standards for the AgNPs synthesis process were established using the mean of the particle siz**e** distribution and the standard deviation of the particle size distribution of the synthesized AgNPs (Şimşek *et al.* 2013).

STEP 1: Identify the objectives for optimizing the performance of AgNPs.

STEP 2: Determine AgNPs performance requirements.

STEP 3: Synthesis of AgNPs and influences on their levels.

STEP 4: Identify materials and techniques for optimization.

STEP 5: Using MINITAB (Karhan *et al.* 2017).

In a 2000 ml beaker, as reducing agent, 0.2% starch is placed in the magnetizer at T=65°C. 75 ml of 0.001 M $AgNO_3$ solution was added to the mixture after mixing for 10 min. The amount of glucose from a 0.1 M glucose solution added to the mixture was assessed by the glucose/$AgNO_3$ ratio. Once the correct amount of 0.1 M NaOH solution had been added, the pH of the mixture was adjusted. The reducing agent glucose transformed the ions (Ag^+) into metallic silver in the alkaline soda hydroxide solution (Ag^0).

For the experiments 1 and 3, the glucose solution was replaced by a quantity of 0.1 M ascorbic acid solution and for the experiment 2 and 4 a 0.01 M tannic acid solution was used with a pH 9 and 9.5.

This reduction mechanism can be seen in the following Equation 2.7. In this way, it has been provided that the mixture has been mixed at a certain temperature for 1 h and the occurrence of a yellow color can be seen up to the end of this period (Karhan *et al.* 2017).

$$2AgNO_3 + C_6H_{12}O_6 + 2NaOH \longrightarrow 2Ag^0 + C_6H_{12}O_7 + 2NaNO_3 + 2H_2O \quad (2.7)$$

Three factors that each of them has five mix levels with the effect on the AgNPs' synthesis quality have been determined as the glucose/$AgNO_3$, Ascorbic/$AgNO_3$ mole ratios, reaction temperature, and pH of the mixture via preliminary experiments. In the literature, these selected parameters, which are the controllable factors, have been commonly used to obtain the optimum AgNPs (Ceran *et al.* 2019).

2.3.2 Characterization of silver nanoparticles

a) UV-Vis spectrophotometry of AgNPs

UV-Vis spectrophotometer (Figure 2.3) is an extremely practical, straightforward, and sensitive method for analyzing metal nanoparticles. It is an effective method for characterizing the synthesized NPs. Absorption spectra can demonstrate the creation of artificial AgNPs in solution (Singla *et al.* 2022).

Transmitted light intensity is measured and compared to an incident light measurement in order to draw conclusions about the sample. Typically, wavelengths between 400 and 800 nm are utilized to demonstrate the presence of nanoparticles (Karhan *et al.* 2017).

Figure 2. 3 Image of the UV-Vis spectroscopy device

b) Temperature

The temperature T has a significant impact on the size and shape of AgNPs' produced through biosynthesis. Studies have shown that as the temperature of the reaction increases, the size of AgNPs decreases, leading to changes in their shape (Raus *et al.* 2021).

c) pH

Changing the pH value during AgNPs' production has been examined in a prior work as a means of altering their form, size, and stability. During the creation of AgNPs', a pH of 7 was determined to be optimal for assuring the reduction of Ag^+ to Ag^0, and a ph range of 7-9 produced the greatest number of synthesized nanoparticles (Bergal *et al.* 2022). Several investigations have demonstrated that the generation rate of AgNPs rises with pH (Zivyar *et al.* 2021)

d) Thermal conductivity

Thermal conductivity was measured using a hot-disk thermal constant analyzer at room temperature (Coetzee *et al.* 2020). Thermal conductivity is the key property that depends on the relevant parameters of nanoparticle material, volume fraction, size, aspect ratio, thermo-physical properties of the base fluid, temperature, and surfactant.

Thermal conductivity refers to the ability of a material to conduct heat. When it comes to AgNPs (Silver Nanoparticles), their thermal conductivity is influenced by several factors, including their size, shape, surface properties, and crystal structure (Steinhardt *et al.* 2022). The small size of AgNPs allows them to effectively scatter phonons (quantum particles of heat), leading to increased phonon-phonon interactions and, consequently, higher thermal conductivity (Zhou *et al.* 2022).

Various equations in the literature can be used to determine the thermal conductivity of nanofluids. However, in this particular study, the thermal conduction coefficient was determined through experimental means. The measurement of thermal conductivity coefficients was carried out using the KD2 Pro device manufactured by Decagon Devices Inc., which utilizes the hot-wire method. It's worth noting that the device has a December error of ±5% Figure 2.4 illustrates the setup of the device used for measuring the thermal conduction coefficient. To ensure accurate results, the experimenters maintained a constant temperature during the measurements by employing a cooling jacket, as depicted in Figure 2.4. This precaution was necessary due to the KD2 Pro thermal conductivity meter's high sensitivity to temperature changes.

Figure 2. 4 Thermal conductivity

e) Electrical conductivity

Electrical conductivity is a measure of a material's ability to carry an electric current." Electrical conductivity is a physical property that describes the ability of a material to allow the passage of electric current through it (Chi *et al.* 2019). Conductive materials, such as metals, have high conductivity, meaning they readily allow the movement of electric charges. Insulators, on the other hand, have low conductivity, making it difficult for electric current to flow through them (Htwe *et al.* 2022).

The electrical conductivity of silver nanoparticles refers to their ability to carry electrical charges. Silver nanoparticles exhibit exceptional conductivity due to their unique nanoscale properties, such as their small size, high specific surface area, and crystalline structure (Shakhatreh *et al.* 2022).

f) Zeta-sizer

The Zetasizer is a device developed to measure the average particle size of nanoparticles. The average nanoparticle size was determined to be between 25 and 40 nm (Hadebe *et al.* 2022).

The Zetasizer is an instrument commonly used to measure the particle size, size distribution, and zeta potential of nanoparticles, including Silver Nanoparticles (AgPNs) (Karhan *et al.* 2017). It utilizes the technique of Dynamic Light Scattering (DLS) to determine the hydrodynamic size of particles in a liquid suspension and the zeta potential, which is a measure of the surface charge (Bamal *et al.* 2021).

The stability of the nanofluids was assessed using the Malvern Zetasizer Nano ZS instrument (Figure 2.5). This device employs a 632 nm HeNe laser and a detection angle of 173°C to conduct measurements of both zeta potential and zeta size.

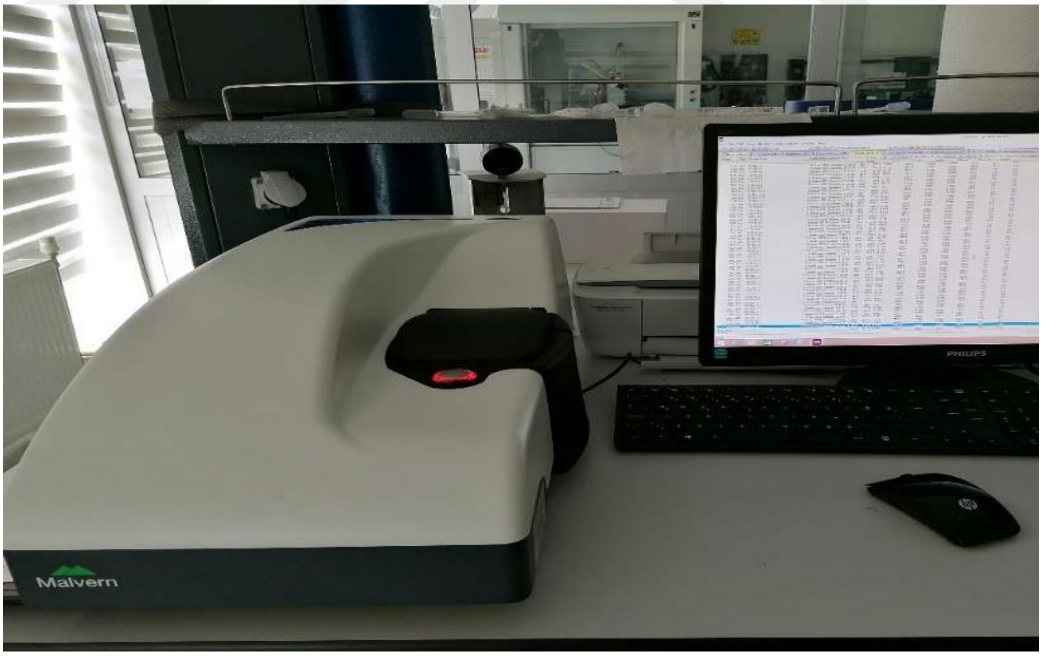

Figure 2. 5 Image of the device where zeta potential and particle size distribution analyses were performed

3. RESULTS AND DISCUSSION

The experiments were perfomed by using 2^2 Full factorial design and mix details were transfereed to the Table 3.1.

Table 3.1 Full factorial design and mix details

Exp. No	Symbol	A (solid to liquid ratio)	B (Reducing agents)	C (pH)
0	REF	3.5	Glikoz	9
1	15AA9	1.5	AscorbicA	9
2	15TA95	1.5	TannicA	9.5
3	35AA95	3.5	AscorbicA	9.5
4	35TA9	3.5	TannicA	9

3.1 Results

Results were given in Table 3.2

Table 3.2 Features of the synthesized AgNPs

Symbol	TC (W/m*K)	EC (µS/cm)	Absorbans@410-420 cm^{-1}	Zeta potential (mV)	Particle size (nm)	Mobility (µm.cm/µS)
REF	0,707±0,0389	80	4000	29,66±0,550	75,2±1,369	2,32±0,043
15AA9	0,771±0,0193	50,2	500	16,3±0,818	199,5±3,292	1,27±0,061
15TA95	0,648±0,0086	46	3900	19,3±2,551	92,2±5,830	1,53±0,202
35AA95	0,758±0,0394	129,4	1200	27,3±1,153	143,5±0,416	2,13±0,097
35TA9	0,767±0,0766	96,1	4000	26,1±1,877	108,3±1,021	2,05±0,147

3.2 Thermal Conductivity

The thermal conductivity of AgNPs decreased with increasing solid-to-liquid ratios. The presence of solid silver nanoparticles in solution can increase the overall thermal conductivity of the system, as solids generally have a higher thermal conductivity than liquids (Figure 3.1). Increasing the proportion of solid silver nanoparticles can therefore lead to an increase in the thermal conductivity of the solution. Ascorbic acid has the highest thermal conductivity, while glucose and TA have low thermal conductivities. The pH also shows a decrease in thermal conductivity from 9 to 9.5.

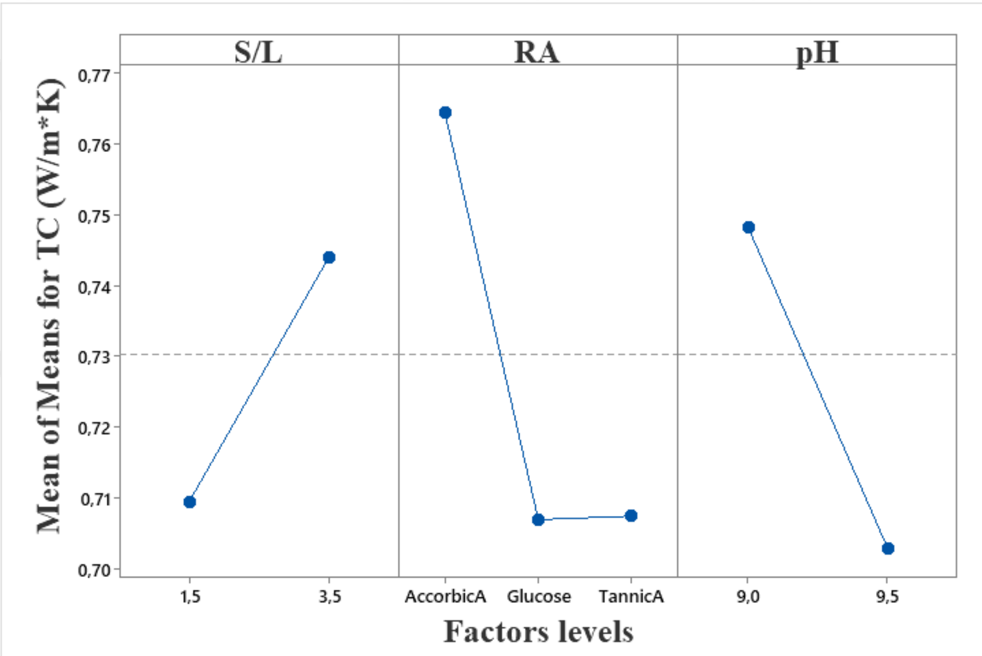

Figure 3. 1 Main effect plot for thermal conductivity of synthesized AgNPs

3.3 Electrical Conductivity

As the solid-liquid ratio increases, the electrical conductivity increases by 50 to 100 µs/cm (Figure 3.2). An increase in the proportion of solid silver nanoparticles in the solution can lead to an increase in electrical conductivity, as the nanoparticles act as electrical conductors. Ascorbic acid has a high conductivity compared with glucose and TA 80 µs/cm and 70 µs/cm. An increase in electrical conductivity was observed at pH

9 to 9.5. This increase is due to the fact that pH has an effect on the electrical conductivity of the silver nanoparticle solution. This is because the concentration of H+ or OH- ions in the solution can vary, which can influence electrical conductivity. Extremely acidic or basic conditions can alter the stability of silver nanoparticles, thus affecting their electrical conductivity.

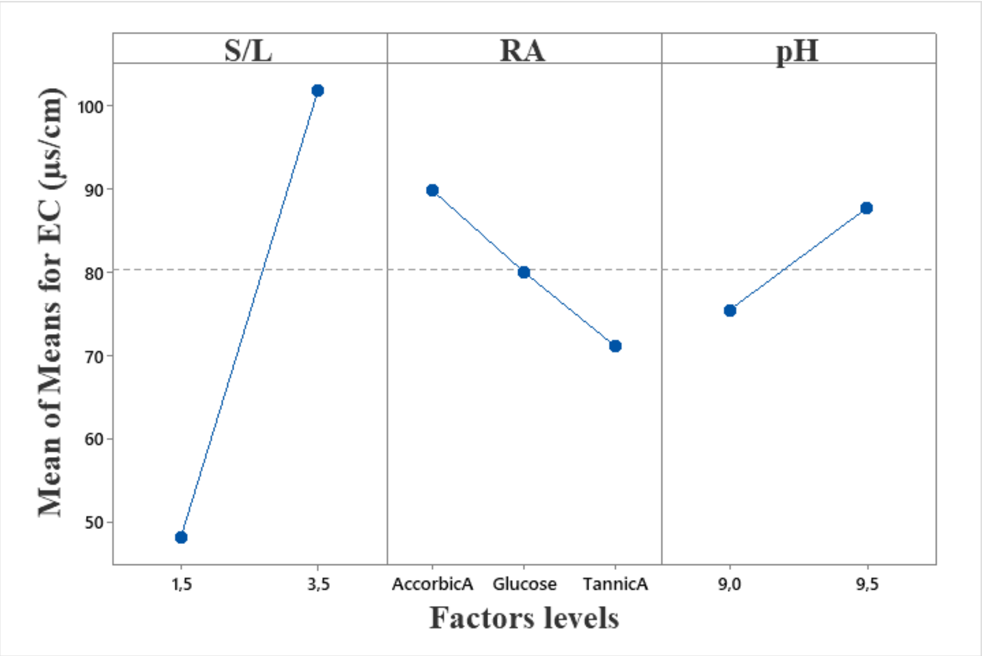

Figure 3. 2 Main effect plot for thermal conductivity of synthesized AgNPs

3.4 Mobility

The solid/liquid ratio represents the proportion of solids (AgNPs) to liquids in the solution. It affects the agglomeration and dispersion behavior of nanoparticles. The main effect plot shows that mobility values increased with an increasing solid/liquid ratio. An increase in the solid/liquid ratio can lead to an increase in particle-particle interactions and a reduction in mobility due to increased aggregation.

Glucose has the highest mobility, influencing the mobility of the synthesized AgNPs. It interacts with the particle surface, affecting the charge and stability of the AgNPs, which leads to the formation of a protective layer around the AgNPs, influencing their interactions with the surrounding medium and their mobility (Figure 3.3). Both TA and AA, which have low mobility 1.7 µm.cm/µs and 1.8 µm.cm/µs respectively.

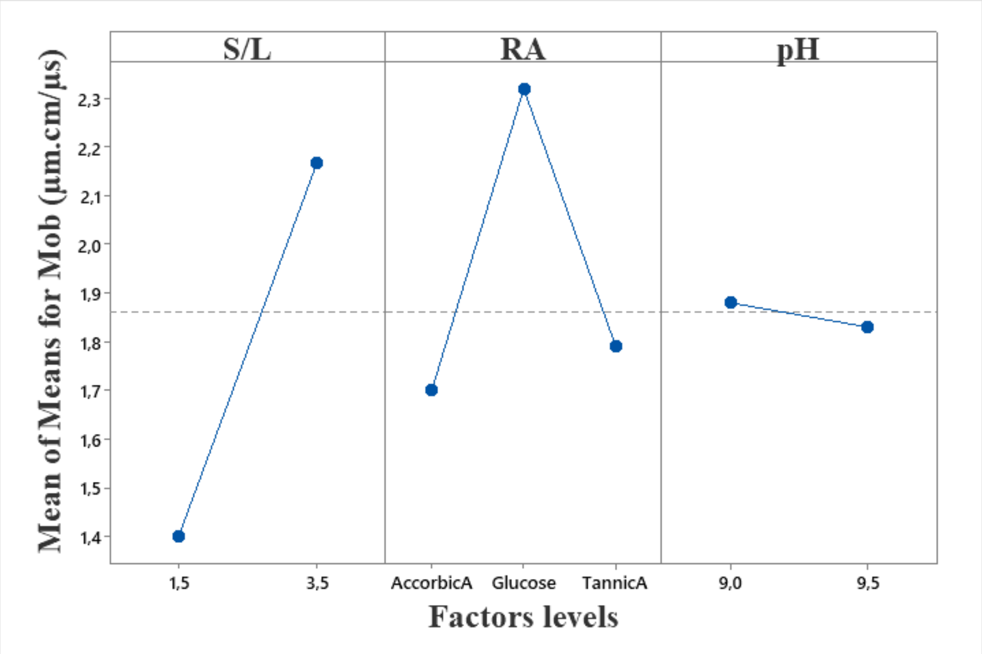

Figure 3. 3 Main effect plot for Mobility of synthesized AgNPs

3.5 Absorbance

UV-Vis was performed to determine whether the synthesis of AgNPs is done or nor. UV-Vis analysis could be seen in Appendix 1, Figure A 1.1.

The absorbance of AgNPs increases with increasing solid/liquid ratio (Figure 3.4). Glucose and tannic acid have the highest absorbance peaks and the pH also shows a decrease in the absorbance.

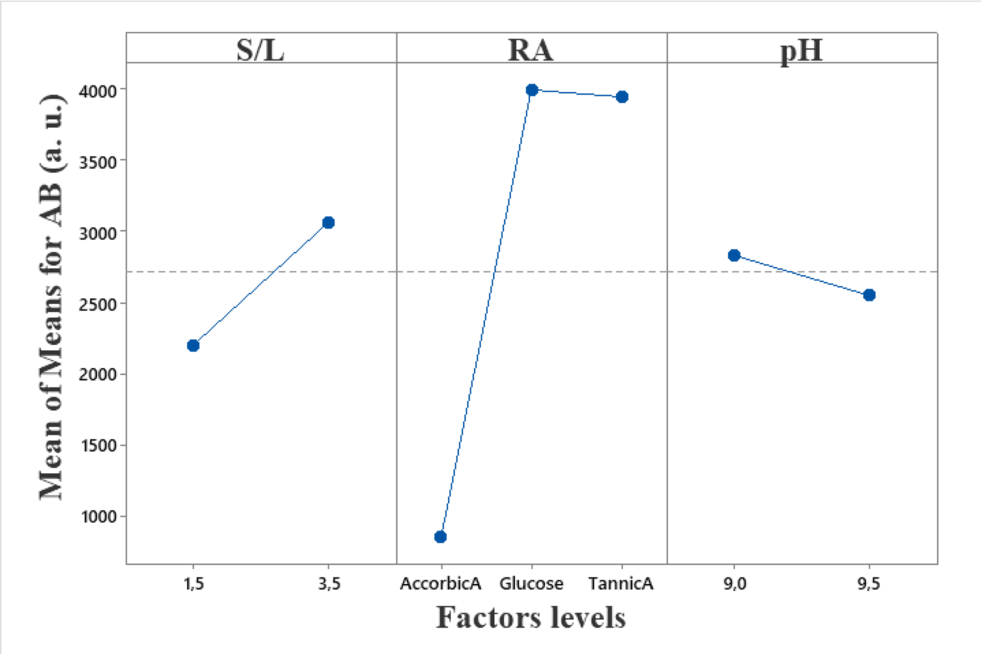

Figure 3. 4 Main effect plot for Absorbance of synthesized AgNPs

3.6 Zeta Potential

The solid/liquid ratio refers to the proportion of solid nanoparticles to liquid solvent in the synthesis of AgNPs. Changes in this ratio can affect the degree of dispersion, agglomeration, or aggregation of the particles. Agglomeration of nanoparticles can alter their surface charge and, consequently, their zeta potential. The main effect plot for the solid/liquid ratio would show an increase in zeta potential with increasing the solid/liquid ratio by 18–28 mV (Figure 3.5).

The reducing agent with the highest zeta potential peak is glucose 30mV, bearing in mind that the presence of glucose also affects the zeta potential of AgNPs, as glucose interacts with the surface of AgNPs, potentially modifying their charge and zeta potential, compared with tannic acid and ascorbic acid having 23mV, 22mV respectively. While the zeta potential of pH decreases slightly.

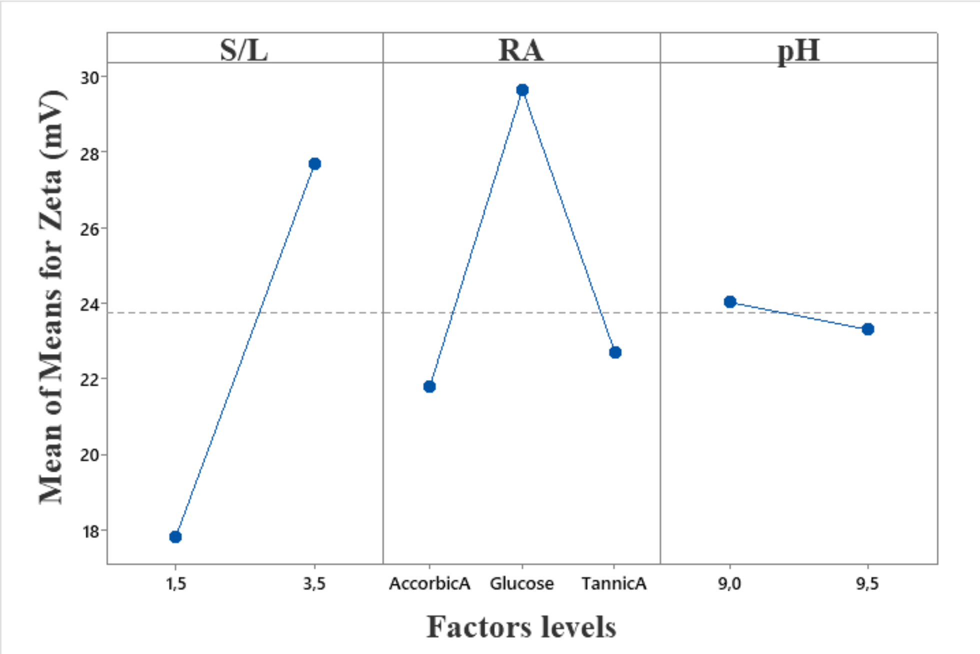

Figure 3. 5 Main effect for Zeta potential of synthesized AgNPs

3.7 Particle Sizer

The main effect plot shows that particle size decreases with increasing solid/liquid ratio. The solid/liquid ratio may have an impact on the size of the AgNPs synthesized. Higher solid/liquid ratios may favor smaller particle sizes due to a higher concentration of silver ions available for nucleation and growth.

Ascorbic acid has a high particle size, while glucose and tannic acid are low. Concentration and interaction with silver ions influence the reduction kinetics and subsequent growth of nanoparticles. Higher concentrations of reducing agents lead to faster reduction and, in some cases, smaller particle sizes. However, above certain concentrations, particle size may start to increase due to aggregation.

A slight decrease in particle size is observed with increasing pH. An increase or decrease in pH can influence the surface charge of nanoparticles, affecting their stability and interaction with the surrounding medium. The main effect plot for pH shows that increasing pH (9–9.5) results in lower mobility due to reduced particle aggregation (Figure 3.6).

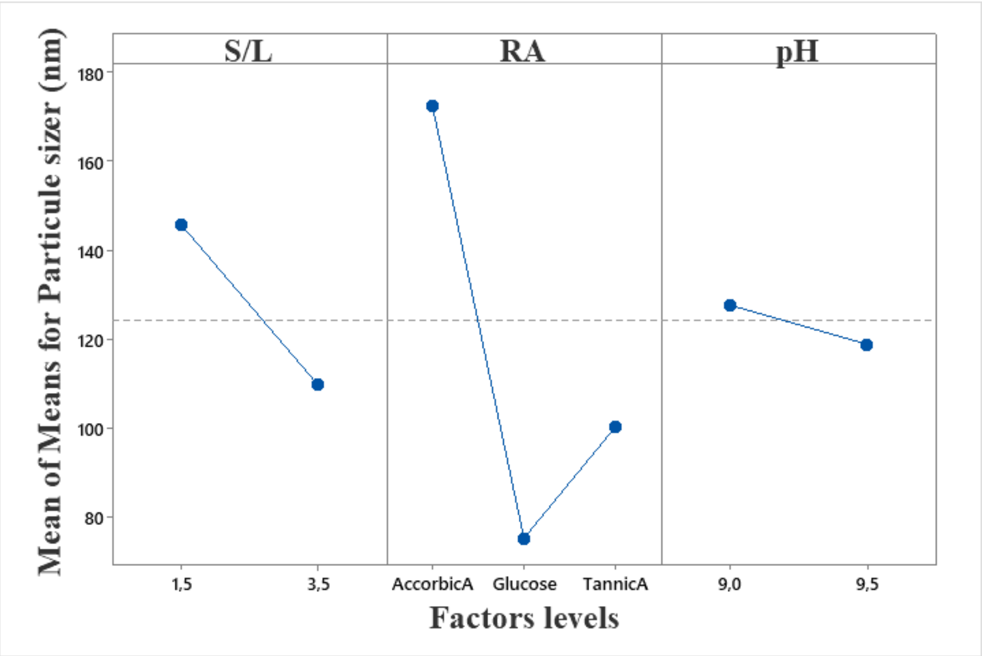

Figure 3. 6 Main effect plot for Particle sizer of synthesized AgNPs

3.8 Fourier-Transform Infrared Spectroscopy (FTIR)

We can learn about the structure, composition, and functional groups of a sample by using Fourier transform infrared spectroscopy (FTIR). By comparing chemical and functional groups, we can determine whether the reference chemical for a given substance is identical to the chemical structure of organic compounds using FTIR spectroscopy data. By examining a sample's functional groups, however, we can only gain a limited understanding of its chemical structure.

To analyze silver nanoparticles using FTIR spectroscopy, the functional groups and bonding structure of Ag NP molecules are investigated in detail. Figure 3.7 displays the findings from an FTIR examination of molecules at various weight percentages.

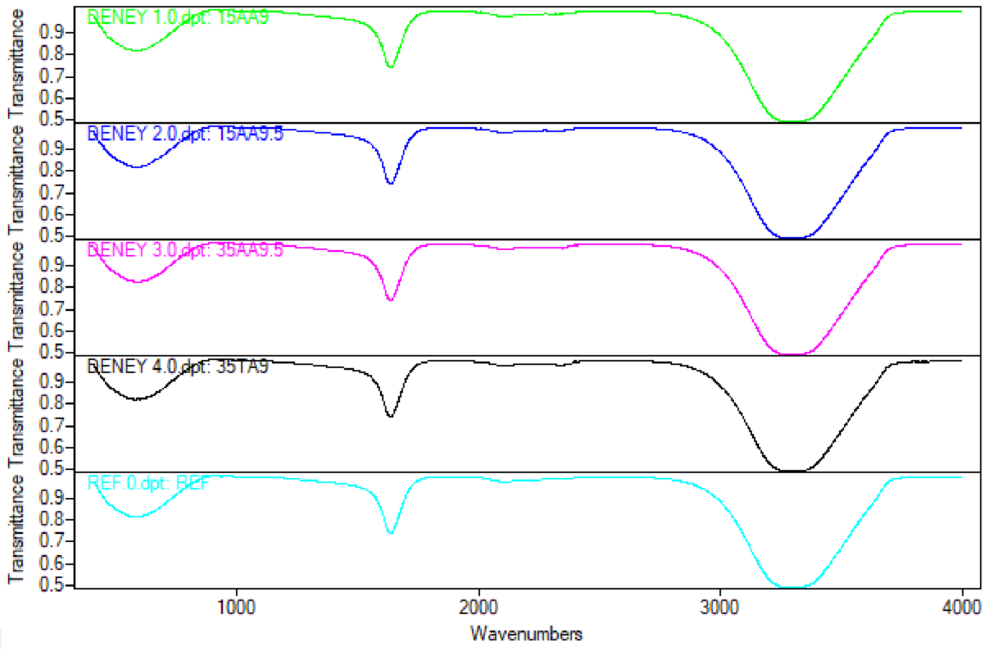

Figure 3. 7 FTIR spectrum

The spectrum displays a broad peak at 3401 cm^{-1}, attributed to the O-H stretching vibrations of the molecules. This peak is associated with the O-H bond stretching vibrations in ascorbic acid and tannic acid. The most recognizable features in the most reported IR spectra of AgNPs are two bands in the middle of the spectrum.

One is the band around 1720 cm^{-1}. This peak is attributed to the C=O bond stretching vibrations (ketones and aldehydes) present in certain functionalities of ascorbic acid, and it is also attributed to the carbonyl bond stretching vibration (C=O) in the carboxylic acid groups (COOH) of tannic acid. The other band appears at around 1617 cm^{-1}.

This peak is associated with the C=C bond stretching vibration in the benzene ring present in ascorbic acid and also with the carbon-oxygen double bond stretching vibration (C=C=O) present in the aromatic rings of tannic acid. An absorption peak around 600 cm^{-1} is also observed, attributed to the stretching vibrations of carbon dioxide (CO_2).

4. CONCLUSIONS AND RECOMMENDATION

In this study, in which silver nanoparticle AgNPs samples were prepared and characterized with the Taguchi L4 experimental design. The experiments were carried out using 2^3 complete factorial designs and Main and interaction effects on selected responses, such as the mean and standard deviation of the size distribution of synthesized AgNPs particles, were analyzed statistically via the Taguchi design, and the following results were obtained:

- ✓ While the thermal conductivity of AgNPs decreased with increasing ratio solid/liquid, ascorbic acid has the highest thermal conductivity.
- ✓ As the ratio solid/liquid increases, the electrical conductivity increases from 50 to 100 µs/cm, because ascorbic acid leads to a high conductivity.
- ✓ The solid/liquid ratio represents the proportion of solids (AgNPs) to liquids in the solution, Glucose leads to the highest mobility.
- ✓ The highest productivity was obtained by tannic acid at the ratio of 3.5 solid/liquid, and the level of pH=7.
- ✓ An increase in the zeta potential with an increase in the solid/liquid ratio of 18-28 mV and the glucose has the highest zeta- potential.
- ✓ The main effect plot shows that particle size decreases with increasing solid/liquid ratio. Ascorbic acid causes a high particle size.

The glucose/$AgNO_3$ and ascorbic/$AgNO_3$ molar ratios were shown to have the greatest influence on AgNPs particle size dispersion. The findings demonstrate that the lowest variances AgNPs are produced at the greatest Ascorbic/$AgNO_3$ molar ratios.

As a result, it can be said that the higher-quality AgNPs production process is possible by adjusting Ascorbic/$AgNO_3$ molar ratio. It is important to note that applying the suggested methodology led to rather significant rates of improvement in the standard deviation of the particle size distribution in the AgNPs production process.

It is important to note that applying the suggested methodology led to rather significant rates of improvement in the standard deviation of the particle size distribution in the AgNPs production process.

To accomplish a high-quality, large-scale manufacturing process, it should be done to minimize the production variance of nanomaterials.

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APPENDICES

APPENDIX 1. UV-Vis analysis of AgNPs

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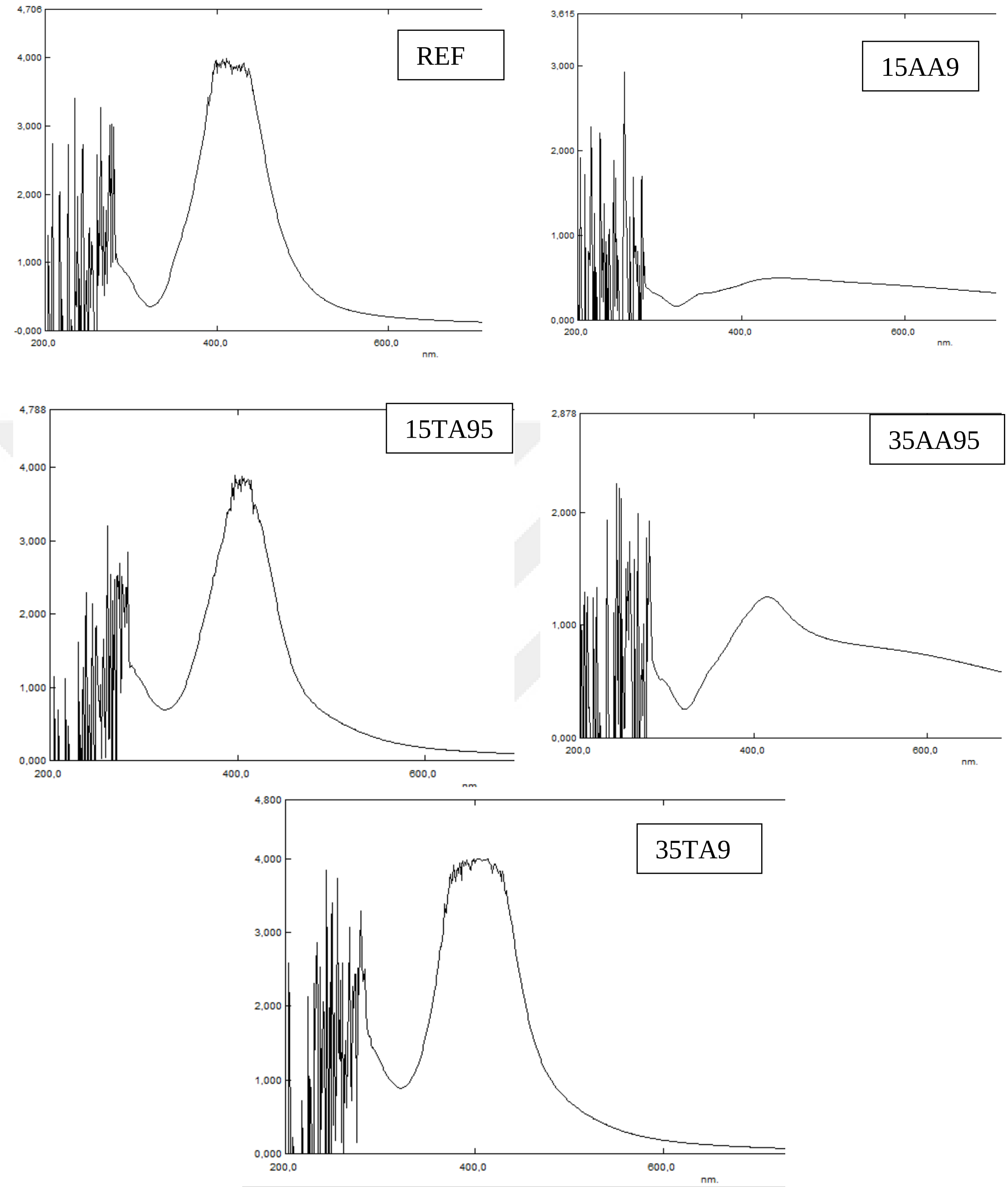

Figure A 1.1 UV-Vis analysis of AgNps

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