EVŌQ Nano: Enhancing Silver Nanoparticle Concentration Through Dielectrophoresis and Laser-Induced Nanoplasmonics

Josh Woolley

Brigham Young University

Applied Physics Capstone Project

Dr. David Allred

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Executive Summary

This report introduces an innovative method to enhance the concentration efficiency of EVQ-218, optimizing production while reducing manufacturing costs at EVŌQ nano. As demand for high-quality silver nanoparticles (AgNPs) grows across various industries, improving yield while maintaining cost-effectiveness is critical to maintaining a competitive edge. My research demonstrates that integrating dielectrophoresis (DEP) and laser-induced nanoplasmonics (LINP) offers a scalable, energy-efficient approach to nanoparticle manipulation, enabling precise control over particle concentration while minimizing particle loss.

By leveraging DEP forces and LINP, nanoparticle yield would significantly improve, leading to greater solution uniformity and increased efficiency. Additionally, the optimized process lowers operational costs by reducing material loss and energy consumption. These techniques can be adapted for both small-scale research and large-scale manufacturing with minimal modifications to existing workflows. Their integration into EVŌQ nano's production line would also contribute to a more sustainable manufacturing process by reducing reliance on excess reagents and energy-intensive separation methods.

To assess the feasibility of this approach, I recommend conducting pilot tests within EVŌQ nano's production facility to refine process parameters and evaluate large-scale implementation. A collaborative effort between the R&D and manufacturing teams will ensure seamless integration and maximize efficiency gains. This report provides a detailed analysis of DEP and LINP, including experimental findings and process optimizations. I encourage senior management and the R&D team to review these findings and consider the next steps for implementation.

Introduction

EVQ-218 is a novel silver nanoparticle (AgNP) with unparalleled antimicrobial properties, offering the potential to revolutionize medical devices and save hundreds of thousands of lives. EVŌQ nano's patented laser ablation technology produces EPA-approved AgNPs that are perfectly spherical and uniformly distributed in solution, making them uniquely suited for biocompatible applications (Kennon, 2024). However, a significant challenge remains. Current production methods yield low concentrations of only 10 to 20 particles per million (PPM), which is insufficient for many medical and industrial uses. To meet increasing demand, medical device companies have requested dozens of liters of product for testing purposes at concentrations exceeding 100 PPM.

Currently, EVŌQ nano relies on nitrogen blowdown (NB) chambers and rotary evaporators (Rotovap) to concentrate AgNPs, but both methods have major limitations. NB chambers maintain particle morphology but operate at an extremely slow evaporation rate of 7–10 mL per hour, requiring several days to concentrate a single liter of solution, far too slow for industrial scalability. Rotovaps, on the other hand, can rapidly concentrate AgNPs within hours but cause morphological changes due to excessive heat and agitation, reducing the nanoparticles' antimicrobial efficacy. Without an efficient and scalable concentration method, EVŌQ nano will be unable to meet production demands or fully capitalize on the potential of EVQ-218.

A more effective approach would involve integrating alternative concentration techniques that enhance scalability without compromising AgNP integrity. This report explores dielectrophoresis (DEP) and laser-induced nanoplasmonics (LINP) as innovative solutions to precisely control AgNP movement and aggregation in a flowing solution. DEP uses electric field gradients to selectively manipulate nanoparticles, offering a non-invasive, energy-efficient method to increase AgNP concentration while maintaining their shape and dispersion. LINP takes advantage of localized surface plasmon resonance (LSPR) to optically control AgNP clustering, providing additional refinement to the concentration process. By combining DEP and LINP, EVŌQ nano can achieve a high-throughput, scalable, and morphology-preserving solution for nanoparticle concentration.

This report will evaluate current concentration challenges, present scientifically supported industrial methods, and provide evidence-based recommendations for implementing DEP and LINP in tandem with EVŌQ nano's manufacturing process. By leveraging these advanced technologies, EVŌQ nano can overcome existing limitations, improve production efficiency, and secure a competitive edge in the growing AgNP market.

Problem Description

EVŌQ nano has developed a groundbreaking silver nanoparticle (AgNP) product, EVQ-218, which exhibits strong antimicrobial properties due to its precise size, uniformity, and surface chemistry. Notably, EVQ-218 is the only AgNP product approved by the EPA, highlighting its safety and effectiveness in antimicrobial applications. Unlike traditional silver nanoparticles, EVQ-218 is non-ionic, making it non-toxic to the body while maintaining high efficacy against a wide range of pathogens (Kennon, 2024; Abbas, 2024)).

The non-ionic nature of EVQ-218 eliminates the risk of silver ion release, which can cause cytotoxicity in biological systems, making it suitable for medical applications such as wound healing, surgical coatings, medical devices, and antimicrobial textiles (Abbas, 2024). Additionally, its optimized surface area and controlled dispersion enhance bioavailability, ensuring consistent antimicrobial action without compromising human cell health. Its unique formulation also allows for greater stability in complex formulations, making it a superior alternative to conventional silver-based antimicrobials used in healthcare, water purification, and consumer products.

EVQ-218 is produced by ablating the surface of pure silver with a Class 4 laser, while a fluid medium transports the resulting nanoparticle plume to a collection site. However, scaling up production while maintaining the integrity of the nanoparticles remains a significant challenge. Currently, production yields silver concentrations of 10-20 mg/L (PPM), yet medical device companies require concentrations exceeding 100 PPM for testing. Increasing the silver concentration directly from manufacturing has proven difficult. Lowering the fluid flow rate, which should theoretically increase nanoparticle concentration, leads to excessive photon exposure, altering particle morphology and causing agglomeration, rendering the solution unusable.

Existing concentration techniques, such as nitrogen blowdown (NB) chambers and rotary evaporators (Rotovaps), each have significant limitations that hinder their suitability for large-scale production. NB chambers effectively preserve nanoparticle integrity but have a slow evaporation rate of only 7–10 mL per hour, requiring three to five days to reduce a one-liter solution to 100 mL. This extended processing time makes the method impractical for high-throughput applications. Additionally, NB chambers rely on compressed nitrogen supplied by in-house generators and compressors, which must run continuously for days, leading to high operational costs and energy consumption.

In contrast, Rotovaps can concentrate solutions within hours, making them far more time efficient. However, the high kinetic energy and heat exposure during the evaporation process degrade nanoparticles, diminishing their structural stability and reducing their antimicrobial effectiveness (Natsuki, 2015). As a result, while Rotovaps offer a faster alternative, they compromise nanoparticle quality, limiting their applicability for sensitive formulations. These drawbacks highlight the need for an alternative concentration method that balances efficiency, scalability, and nanoparticle stability.

Without an efficient and scalable concentration method, EVŌQ nano will be unable to meet the growing demand from medical device companies. Developing a new concentration technique that preserves nanoparticle integrity while enabling high-volume production is critical for the company's future success. Two alternative methods of concentration are discussed in detail below.

Potential Solutions

To meet market demands for rapid solution concentration, EVŌQ nano must develop an advanced method that accelerates the process without altering particle morphology. The ideal approach should be seamlessly integrated into the manufacturing process, reducing complexity, enhancing efficiency, and ensuring precise control over the final concentration. Two promising techniques that align with these criteria are dielectrophoresis and laser-induced nanoplasmonics, both of which offer potential for high-speed, scalable nanoparticle concentration.

Dielectrophoresis

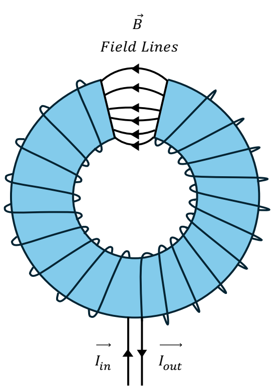
Dielectrophoresis (DEP) is a promising technique for manipulating and concentrating AgNPs in a constant-flow water system. It has been a focus of research for the past 2 decades with biomedical applicability to bacterial, viral, and cancer detection (Sarno, 2020). DEP relies on the interaction between an applied non-uniform electric field and the dielectric properties of nanoparticles. When an external AC field is applied, nanoparticles interact with the alternating magnetic field and experience a force that moves them toward regions of higher or lower electric field intensity, depending on their polarizability relative to the surrounding medium. This allows for the selective concentration and separation of AgNPs without requiring excessive heating or chemical additives (Wang, 2025). The advantage of DEP over similar methods such as electrophoresis and electrorotation, is the particles do not need to be charged. This characteristic is vital for EVQ-218 because the AgNPs are non-ionic.

DEP can be implemented using microfluidic channels lined with electrode arrays carrying AC or DC current. These electrode patterns generate strong field gradients that selectively trap and concentrate AgNPs from the flowing water (Chen, 2009). Unlike traditional filtration or evaporation techniques, DEP is advantageous because it operates at ambient temperatures. Additionally, tuning the frequency of the applied field allows for precise control over the concentration process, enabling separation based on nanoparticle size or composition (Dimaki, 2022). However, DEP requires careful electrode design and optimization of the applied voltage to prevent excessive particle aggregation or clogging.

Microfluidic tubing is the primary method of DEP experimentation. This tubing is crafted using photolithography to ensure uniformity and accuracy of tubing size. The throughput of microfluidic tubing is measured in μL/h (Dimaki, 2022). This is not sufficient for the desired throughput of EVQ-218. EVŌQ nano produces EVQ-218 at a rate of 5-7 mL/s, pushing far more volume per unit of time than microfluidic tubing. For DEP to be effective at the current and future manufacturing rate of EVŌQ nano, it must be scaled appropriately and produce enough force to manipulate AgNPs flowing at a rate of mL/s in Teflon tubing with a diameter of 1.2 cm. Crucially, the flow must be laminar flow to maximize the DEP effect. This can be done by creating a section of tubing with glass capillary tubes bound with heat shrink tubing equivalent to the diameter of tubing used in production.

Figure 1

Magnetic Field Lines of a Gapped Toroid



A promising engineering model for implementing DEP in high-throughput systems is inspired by the recently expired U.S. Patent 6,095,337, designed by Vladimir Saveliev. This patent describes a mechanism that employs a gapped toroid to selectively separate electrically conductive materials from non-conductive ones. While this technology was originally developed for industrial mining applications, particularly for the extraction of precious metals such as gold and silver, its underlying principles can be adapted to enhance the EVQ-218 manufacturing process. Specifically, the alternating magnetic field generated by the toroid exerts a force, $\overrightarrow{F_B}$, on nanoparticles, directing them as they flow perpendicular to the field through the toroidal gap.

As illustrated in Figure 1, the presence of a gap in the toroidal structure disrupts the otherwise uniform magnetic field, causing the field lines to bulge outward. This non-uniformity in the field distribution results in a force that pushes particles toward the outer rim of the toroid, affecting their trajectory. The underlying principle leverages the interaction between the alternating magnetic field and the dipoles of conductive nanoparticles, thereby enabling efficient separation and manipulation of particles based on their electrical and magnetic properties.

The system is designed to operate with a high frequency alternating current (AC) voltage supplied to the coils of the toroid. For effective manipulation of sub-100 nm particles, the optimal frequency range is typically above 40 kHz. This high frequency alternating magnetic field induces a magnetic moment within the nanoparticles, leading to the generation of Foucault (eddy) currents (Saveliev, 2000). These eddy currents, in turn, interact with the surrounding magnetic field, producing a net force that influences the motion of the nanoparticles. By precisely tuning the frequency and voltage of the applied AC current, AgNPs can be manipulated and directed in a controlled manner.

The force $\overrightarrow{F_B}$ acting on a nanoparticle is highly dependent on the skin depth of the alternating magnetic field. The skin depth, δ, is mathematically defined as:

$$\delta = \frac{1}{2\pi}\sqrt{\frac{R}{f}}$$

where:

- R is the electrical resistivity of the material
- f denotes the frequency of oscillation of the applied AC current

The skin depth determines how deeply the alternating magnetic field penetrates into the nanoparticle. Two limiting cases arise based on the relationship between the skin depth and particle size d:

- If $\delta \gg d$ (the skin depth is much larger than the particle size), then the magnetic force $\overrightarrow{F_B}$ is negligible, effectively approaching zero.
- If $\delta \ll d$ (the skin depth is significantly smaller than the particle size), then the force is maximized, and its magnitude is given by:

$$\overrightarrow{F_B} = \frac{1}{4}\alpha_1 V\, \nabla \mathrm{B_0}^2$$

where:

- $\alpha_1$is the real part of the magnetic polarization coefficient
- V represents the volume of the particle
- $\mathrm{B_0}$ is the strength of the magnetic field

A critical factor in optimizing DEP-based nanoparticle separation is understanding the electrical resistivity of AgNPs, which must be determined experimentally. The resistivity directly influences the skin depth and, consequently, the strength of magnetic force. By accurately measuring and characterizing these properties, it becomes possible to optimize the electric field parameters for precise nanoparticle manipulation in a constant-flow system.

Notably, Saveliev's experiments demonstrated that this method could achieve particle velocities of 55.6 cm/s when applied to gold separation in mining applications. This velocity is well above the minimum threshold required to achieve efficient AgNP separation in fluidic systems, particularly in tubing with a 1.2 cm diameter. This highlights the feasibility of scaling the system for nanoparticle separation applications, enabling efficient material sorting in high-throughput conditions.

Laser-Induced Nanoplasmonics

A highly advanced method for concentrating silver nanoparticles (AgNPs) in flowing water is laser-induced nanoplasmonics (LINP). This approach leverages localized surface plasmon resonance (LSPR), a phenomenon in which metal nanoparticles absorb and scatter light at specific wavelengths, generating intense localized electric fields (Di Bartolo, 2015). When a laser is applied to AgNPs in solution, it excites collective electron oscillations, creating nanoscale electric field hotspots that influence nanoparticle motion. By modulating the laser's wavelength, intensity, and focal region, AgNPs can be directed toward specific areas, forming highly concentrated clusters. LINP is particularly effective for particles in the 2–20 nm size range (Stockman, 2011), which aligns with the size distribution of EVQ-218.

Photons, as wave packets of oscillating electric and magnetic fields, interact with nanoparticles when introduced into a medium containing AgNPs. These interactions induce oscillatory motion in the electrons and protons of the nanoparticles, leading to localized electric field enhancement, as depicted in Figure 2a. This effect significantly amplifies the electric field signature of the nanoparticles, reinforcing their plasmonic response (Stockman, 2011; Di Bartolo 2015).

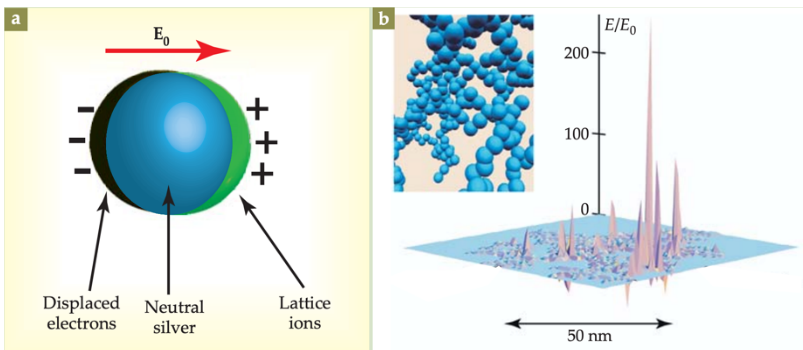


Figure 2 *Localization and Hot Spots of AgNPs*

Note. Adapted from “Nanoplasmonics: the physics behind the applications” by Stockman, 2011, *Physics Today*

As shown in Figure 2b, the enhancement of the electric field surrounding AgNPs under LINP can reach levels exceeding 250 times the initial electric field. This field enhancement plays a critical role in nanoparticle clustering and manipulation, facilitating precise control over particle distribution.

To evaluate the viability of LINP for AgNP manipulation, an experimental study was conducted using EVQ-218. Two 50 mL glass vials were filled with a 12.68 PPM AgNP solution. One vial was exposed to a 405 nm laser applied vertically and a magnetic field from a bar magnet taped to the exterior, while the second vial was kept as a control over a 48-hour period. After laser and magnetic field exposure, AgNPs

Figure 3

LINP Experiment Vials with EVQ-218

Note. Left vial concentrated using 405 nm laser. Right vial control.

visibly concentrated near the bottom of the treated vial (Figure 3), confirming that LINP effectively induces nanoparticle concentration in solution.

To further test the reversibility and stability of the LINP-induced AgNP, the solution was subjected to vortex mixing and ultrasound treatment. Following these procedures, the AgNPs successfully redistributed throughout the solution without agglomeration or fallout, demonstrating that LINP-induced clustering is non-permanent and controllable. These results indicate that LINP is a highly effective, reversible, and scalable method for manipulating AgNPs in fluidic environments.

In high-throughput systems, LINP can be integrated with DEP to achieve greater precision in particle manipulation. This combined approach offers several advantages, including non-contact control, tunable adjustments through laser power, and seamless compatibility with continuous-flow systems. LINP amplifies the electric field signature of AgNPs, significantly enhancing the effectiveness of DEP forces. This increased field strength allows for lower applied voltage and reduced oscillation frequency while maintaining the same level of particle control, improving both energy efficiency and operational stability.

Conclusion

The integration of dielectrophoresis (DEP) and laser-induced nanoplasmonics (LINP) presents a transformative opportunity for EVŌQ nano to overcome current concentration challenges while maintaining scalability, efficiency, and particle integrity. These advanced techniques offer a precise alternative to traditional methods, addressing both the bottleneck in production and the demand for high concentrations of AgNPs. By leveraging DEP's selective manipulation and LINP's enhanced control, EVŌQ nano can achieve greater throughput, improved uniformity, and reduced operational costs. This research provides a scientifically supported pathway toward optimizing EVQ-218 production, ensuring the company remains at the forefront of nanoparticle manufacturing in a competitive and rapidly growing market.

Recommendation

I propose implementing dielectrophoresis (DEP) and laser-induced nanoplasmonics (LINP) in tandem to enhance the concentration of EVQ-218 within EVŌQ nano's manufacturing process. By leveraging DEP's ability to selectively trap and manipulate nanoparticles using electric field gradients alongside LINP for precise nanoparticle aggregation and control, this hybrid approach can maximize efficiency while preserving AgNP morphology. DEP provides a scalable method for initial nanoparticle collection and concentration, while plasmonic enhancement can fine-tune aggregation and ensure high-yield output.

To validate this approach, I recommend conducting pilot studies on the R&D laser at EVŌQ nano to optimize key parameters such as frequency, field strength, laser intensity, and processing speed. Additionally, evaluating the integration of these technologies into existing production pipelines will be crucial for industrial scalability. By combining these two methods, EVŌQ nano can achieve higher throughput, improved particle stability, and a competitive edge in the high-concentration AgNP market, ensuring the company meets the growing demand for its revolutionary product.

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April 16, 2025

Mr. David Nilson
EVŌQ nano
Centre Pointe Business Park
1895 W 2100 S
Salt Lake City, UT 84119

Dear Mr. Nilson,

I am pleased to submit the attached report detailing an electromagnetic-based method designed to enhance the concentration efficiency of EVQ-218. This approach not only optimizes concentration but also presents a cost-effective method that is easily scaled and integrated into the current manufacturing process.

Furthermore, the report outlines the critical challenges in concentrating silver nanoparticles, particularly in achieving scalability, efficiency, and quality control. Specifically, it explores the underlying scientific principles behind dielectrophoresis (DEP) and laser-induced nanoplasmonics (LINP), two cutting-edge methods that offer precise nanoparticle manipulation in constant-flow solutions.

The presented findings provide valuable insight into how DEP forces and LINP effects can be harnessed to optimize particle concentration without compromising morphology. Implementing these technologies in tandem has the potential to revolutionize EVŌQ nano's manufacturing and development processes, ensuring a more reliable, scalable, and high-quality production system. The approach represents a viable and forward-thinking solution to our current limitations.

Please review this report at your convenience and provide feedback through further discussion regarding implementation. If deemed suitable for implementation, I will begin developing and testing this method in conjunction with our manufacturing process.

Thank you for your time and consideration. I look forward to your thoughts.

Sincerely,

Josh Woolley

Josh Woolley