"Sol-Gel Synthesis: From Solution to Solid for Biological Applications"

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Introduction

The global burden of cancer, Alzheimer's, and vascular diseases demands new drug-delivery technologies that minimizes systemic toxicity while improving targeting precision. Although self-administered therapeutics like Ozempic have transformed chronic disease management, current injectable systems lack the ability to actively navigate toward diseased tissues.

This research addresses this gap by developing a new class of self-propelled, injectable nanomotors designed for targeted drug delivery through programmable propulsion and ligand-based guidance.

To fabricate these nanomotors, the study uses the sol–gel method, an adaptable chemical synthesis technique that has gained renewed attention for creating advanced nanomaterials with controlled composition and structure. Originally used for ceramics, the sol–gel process now enables the formation of functional hybrid materials suitable for biomedical applications (Aurobind et al.). Its ability to produce stable, uniform nanoscale networks makes it ideal for engineering nanomotor shells and surfaces that enhance propulsion and drug-loading capacity (Priya, R., et al.).

Over the past year, we have iteratively designed, fabricated, and tested nanomotor prototypes. The next phase will focus on testing gold nanoparticles and exploring possible applications in healthcare. This work represents our first integrated biomedical engineering project and lays the foundation for our future goal.

Objective

Our objective in this phase is to synthesize nanoparticles using the sol–gel method. The purpose of this experiment is to produce ultra-small nanoparticles, which is a critical step in advancing our ongoing research and future applications in healthcare.

Methods

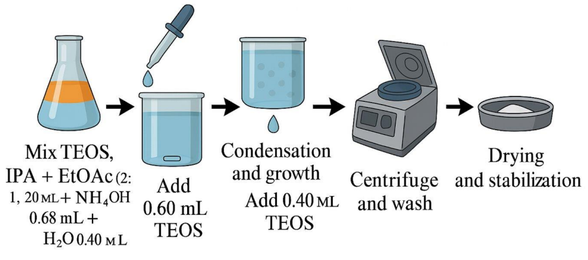

Figure 1. Stöber sol–gel synthesis of silica particles.
TEOS is combined with alcohol, water, and NH_4OH to drive hydrolysis and condensation, followed by controlled TEOS addition, centrifugation, washing, and drying to produce uniform silica particles.

Results

Figure 2. Image of designed spherical, rod-shaped, and helical structures using a 3D printer

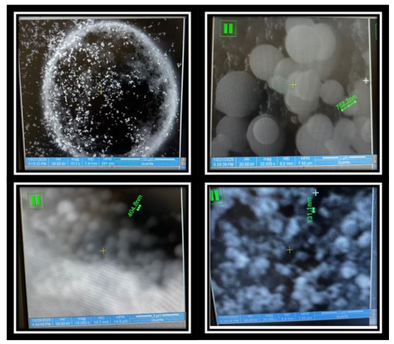

Figure 3. SEM images of particle size and morphology: Trial 2 (top left), Trial 3 (top right), Trial 6 (bottom left), Trial 10 (bottom right).

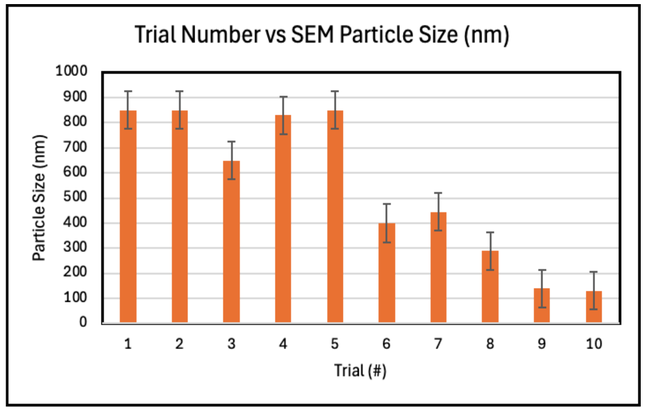

Figure 4. Average SEM-measured particle size as a function of trial number. Error bars represent the standard deviation, illustrating variability in particle size across experimental trials.

Table 1. Summary of experimental parameter variations across silica nanoparticle synthesis trials. The table shows only the variables adjusted in each trial (including TEOS volume, stirring rate, temperature changes, total reaction time, and SEM result) while all other procedural steps were kept constant.

Trial	Variable Changed	TEOS Added (mL)	Stirring Change	Temperature Change	Total Time	SEM Particle Size (nm)
1	Baseline	7.5 + 2.5	1200 after NH_3	55°C	75 min	850-975
2	Increased stirring	7.5 + 2.5	1500 after NH_3	55°C	75 min	850-950
3	Changed TEOS amount & EA amount	6.0 + 2.5	1200 after NH_3	50 → 55°C	70 min	650-850
4	Heat lowered ("slow step")	7.5 + 2.5	1200 after NH_3	40 → 45°C	75 min	830-970
5	No second TEOS	7.5 only	1200 after NH_3	50°C	75 min	850-955
6	No second TEOS + different heat	7.5 only	1200 after NH_3	50 → 55°C	75 min	400-550
7	No 2nd TEOS, slow reaction (3 hr)	7.5 only	1200 after NH_3	40°C	190 min	445-725
8	Lower TEOS + slow reaction	6.0 only	1200 after NH_3	40°C	190 min	290-410
9	Add 20 mL IPA to stop growth	6.0 only	1200 after NH_3	40°C	190 min	140-180
10	Lower TEOS (5 mL) + slow reaction	5.0 only	1200 after NH_3	40°C	190 min	130-175

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Discussion

The results demonstrate that sol-gel synthesized particles exhibit strong variation in size based on controlled changes in reaction conditions. As shown by the SEM particle size trend across Trials 1-10, particle size decreases as TEOS concentration is reduced, reaction time is extended and temperature is lowered. Early trials (Trials 1–5), which used higher total TEOS amounts and shorter reaction times, consistently produced larger particles in the 850–975 nm range.

A clear transition occurs beginning in Trial 6, where removal of the second TEOS addition and adjustment of the temperature profile resulted in a substantial decrease in particle size to the 400–550 nm range. This shift indicates that limiting precursor availability slows particle growth during the condensation stage. The data show that TEOS availability plays a dominant role in controlling final particle size.

Further reductions in particle size were observed in Trials 7 and 8, where longer reaction times and lower temperatures were employed. These conditions promoted slower, more controlled growth, yielding particles between 290 and 725 nm. This trend confirms that extending reaction duration while maintaining reduced thermal energy allows for finer size control.

The smallest particles were produced in Trials 9 and 10, where TEOS concentration was minimized and IPA was added to halt growth, resulting in particle sizes of approximately 130–180 nm. Overall, these results highlight the sensitivity of the sol–gel process to synthesis parameters and confirm that precise control of reaction conditions enables reproducible tuning of particle size for nanoscale applications.

Future Directions

The next phase will include using gold nanoparticles and assessing their properties for potential healthcare applications. Upcoming work will also focus on optimizing nanoparticle synthesis, exploring new fabrication strategies, and using TEM to measure particle shape. Finally, future efforts will aim to improve nanomotor design to further enhance performance and versatility for healthcare applications.

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References

Aurobind, S. V., Amirthalingam, K. P., & Gomathi, H. (2006). Sol–gel based surface modification of electrodes for electroanalysis. *Advances in Colloid and Interface Science, 121*(1–3), 1–https://doi.org/10.1016/j.cis.2006.04.001

Priya, R., et al. (2021). Review on rare earth metals doped $LaPO_4$ for optoelectronic applications. *Solid State Communications, 339*, 114457. https://doi.org/10.1016/j.ssc.2021.114457