THE OHIO STATE UNIVERSITY

Ph.D. Thesis Defense

The William G. Lowrie Department of Chemical and Biomolecular Engineering

"Nanoparticle synthesis using Electrohydrodynamic and Jet mixing"

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Abstract

The translation of bench-scale nanoparticle synthesis procedures to continuous, up-scaled nanomanufacturing operations remains a challenging task. Nanoscale materials and devices hold great promise, however, low throughput and inconsistent quality limit their applications at a large scale. Despite the commercial success of top-down approaches like photolithography and nanoimprint lithography, bottom-up approaches are predominantly bench-scale. The inherent intricacies of reaction or self-assembly kinetics in bottom-up procedures create difficulties in achieving consistent product quality. Scaling up a bottom-up synthesis techniques suffer from erratic product output and poor functionality control. Nanoprecipitation represents one such commonly used bottom-up approach for nanoparticle synthesis. Such nanoprecipitation kinetics are rapid, occurring on the timescale of milliseconds. Mixing in conventional batch reactors fails to achieve concentration/temperature homogeneity on the precipitation timescale. Inhomogeneous kinetics results in a polydisperse nanoparticle population and heterogeneities in size-dependent properties. Hence, the primary goal of this work includes investigating different mixer types based on electrohydrodynamic (EHD) mixing and jet mixing (JM) and their effectiveness in achieving uniform nanoparticle size and properties.

The EHD mixing was assessed through different block copolymer nanoparticles, with size characteristics serving as an evaluation criterion for mixing. Several operating parameters, including the solvent-to-antisolvent ratio and ground-to-electrified needle distance, were used to determine the versatility and limitations of the EHD mixer. A continuous EHD mixing process was developed to demonstrate the potential scalability of the EHD mixer for polymer nanoparticle synthesis. The EHD mixing setup was further investigated for its versatility in producing drug loaded polymer nanoparticles. Hansen solubility and Flory-Huggins interaction parameters were compared to allow for a predictive insight into the hydrophobic encapsulation efficiency. Lastly, the mixing dynamics of the JM reactor were explored to provide guidelines for geometric scaleup. Furthermore, the polymer nanoparticle synthesis was benchmarked against conventional large scaled stirred vessel reactor and industrially relevant T-mixer. In summary, this dissertation work is focused on expanding the capabilities and limits of the rapid mixing platforms through direct fundamental fluid mixing studies and indirect model nanomaterial synthesis and characterization.