INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Microscale mixing in fluidic devices offers several advantages, including reduced sample volume, portability, cost-effectiveness, safe handling of hazardous materials, compact size, and biodegradability. Efficient mixing is crucial for various microfluidic processes, particularly in biochemical and medical diagnostics. Several studies investigated in this thesis focus on enhancing vortex-assisted mixing in microfluidic devices through both passive and active approaches. The challenge lies in achieving efficient mixing in the confined space of microfluidic/nanofluidic pathways, which has led to exploring secondary flows to boost advection over molecular diffusion. This involves implementing passive methods, such as introducing inlet swirl, and active methods, like applying an external electrical field, all within the constraints of a narrow-fluidic channel. The dissertation outlines objectives and analyzes each application in detail across respective chapters.

The first problem explores the mixing of constituent components in a narrow fluidic cylindrical channel under swirling flow conditions. The analytical solution for the flow field, obtained through the separation of variables method, is validated using numerical simulations. The swirl velocity profile, dependent on Reynolds number (Re), shows exponential decay along the channel length. Numerical solutions for the species transport equation, considering Peclet numbers ranging from 10^2 to 10^4, are coupled with the swirl velocity for $0.1 \leq Re \leq 100$. Increasing Reynolds number induces complete fluid rotation, resulting in engulfment flow and significantly enhancing mixing efficiency. Continuing from our prior study of the second

problem, we introduce a tangential (swirl) velocity at the inlet to facilitate effective mixing of inelastic non-Newtonian fluids or solutes at the outlet. This consideration incorporates the non-linear viscous effects inherent in shear-thinning and shear-thickening fluids, utilizing the power-law model. Through numerical solutions of the species transport equation, coupled with the analytically determined swirl velocity, we illustrate that the combination of inlet swirl and shear-thinning fluid properties enhances advection-dominated mixing. Furthermore, higher Reynolds numbers contribute to increased advection dominance, resulting in engulfment flow, chaotic convection, and improved mixing efficiency.

The third problem explores the mixing of soft biofluids within a narrow fluidic device influenced by electroosmotic vortices generated by patterned soft polyelectrolyte layers (PEL) that modulate the electrical double effect. We employ numerical solutions to the transport equations describing solute mixing in the chosen setup and assess the shear-induced kinetics of binary aggregation in the deployed soft matter system. The interplay of forces arising from fluid rheology and PEL's geometric parameters significantly impacts the size and strength of developed vortices, consequently affecting mixing strength in a non-trivial manner. Our investigation demonstrates that higher shear-thinning behavior of constituent components coupled with a larger extent of PEL structure results in enhanced solute mixing (>90%). Furthermore, we estimate the characteristic time of binary aggregation kinetics, crucial for analyzing the mixing of biofluids containing biomolecules, based on the parameters employed in this analysis. The results indicate that an increase in the shear-thinning behavior of solutes leads to a decrease in the characteristic time of binary aggregation kinetics.

In the fourth problem, we investigate non-Newtonian vortex characteristics in a microchannel influenced by a pH-sensitive polyelectrolyte layer (PEL) modulated electroosmotic effects. Using a finite element method-based numerical solver, the developed mathematical framework considers the impact of solution bulk pH (pH_b) and ionic concentration on zeta potential. Across varying pH_b and rheological parameters, the analysis covers PEL space charge density, net body force, and flow patterns. The study reveals that distinct net electrical body force patterns lead to specific flow structures, influencing flow rate and mixing efficiency. Protonic exchange dominance in basic and acidic PEL groups results in pH-dependent net electrical body force, influencing vortex direction and flow rates. Different flow pattern regimes emerge with pH_b ranging from 3 to 11. At pH_b around 4, mixing efficiency is nearly 100% at lower Carreau numbers, exceeding 90% for higher diffusive Peclet numbers in highly acidic liquids. These findings hold significant implications for designing microfluidic/nanofluidic devices for specific pH_b values in mixing and transporting non-Newtonian liquids.