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Topic of Research: Micromixing performance inside passive micromixers

Findings

This dissertation presents an original and systematic investigation into the design, numerical modeling, and performance optimization of passive micromixers operating under low Reynolds number conditions typical of microfluidic applications. Three micromixer configurations were examined, namely a conventional T-shaped micromixer, a vortex-assisted T-shaped micromixer, and a newly proposed Three-Dimensional Serpentine Passive Micromixer (TDSPM). Fluid flow and species transport were analyzed using the Navier–Stokes equations coupled with scalar transport models for both water–dye and nanofluid–dye systems.

The TDSPM, incorporating rectangular inlets and U-shaped serpentine channels, demonstrated enhanced mixing performance by repeatedly splitting, stretching, and recombining fluid streams, thereby promoting chaotic advection. Over a Reynolds number range of 5–250, the TDSPM consistently outperformed the baseline configurations, achieving mixing efficiencies of up to 99% while maintaining moderate pressure losses.

A priority-based machine learning analysis identified Reynolds number and inlet velocity as the most influential parameters governing mixing performance. An optimized configuration (Re = 200, velocity = 4.2 m/s, path length = 25 mm, channel width = 5 mm) achieved a mixing efficiency of 98% with a pressure drop of approximately 0.5 kPa.

The incorporation of an Al_2O_3–water nanofluid with Rhodamine-B dye further enhanced mixing performance, particularly at low Reynolds numbers, highlighting the potential of nanofluid-assisted passive micromixing. Overall, the findings establish the TDSPM as an effective passive micromixer design that offers a favorable balance between mixing efficiency and energy consumption, with applicability in biomedical diagnostics, chemical processing, and lab-on-chip systems.