Design and Mixing Performance of a Hybrid Split-and-Recombine Micromixer toward Nanoparticle Production

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Microfluidic devices are increasingly recognized for their portability and high sensitivity, making them highly suitable for applications ranging from diagnostics to chemical synthesis and biotechnology. Fluid flow in miniaturized systems is typically characterized by low Reynolds and high Peclet numbers, thus requiring very long channels to obtain adequate mixing. To address this challenge, this study investigates a micromixer design that combines a split-and-recombine approach with chaotic flow dynamics to achieve high-efficiency mixing in a compact geometry.

The mixing mechanism within the device is thoroughly examined using Computational Fluid Dynamics (CFD) simulations. The mixing efficiency is quantified in terms of Coefficient of Variance (CoV), which is calculated by analysing cross-sectional images obtained from simulations. The effect of different design parameters on the mixing efficiency is evaluated. Furthermore, the printability of the optimized micromixer design is evaluated using Digital Light Processing (DLP) 3D printing technology. The printed micromixer is then optically analysed to assess the accuracy of the fabrication compared to the Computer-Aided Design (CAD) model.

The performance of the printed device is experimentally tested with coloured fluids at varying Reynolds numbers to validate the mixing efficiency calculated by the model.

The results offer new insights into how specific geometric and operational parameters influence mixing efficiency in the peculiar low Reynolds number situation typical of microfluidics. These insights have potential applications in the optimization of nanoparticle manufacturing processes, particularly in scenarios involving hydrophobic polymer solutions mixed with non-solvents, as well as in the formulation of lipid-based nanoparticles for biomedical applications such as drug delivery and gene therapy.

Keywords: *Micromixer, slit and recombine, chaotic flow, nanoparticle, 3D printing, DLP, CFD simulation, particle tracing.*