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RESEARCH PAPER

Numerical study on shape optimization of groove micromixers

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Abstract The performance of a homogeneous T-mixer can be enhanced significantly by the stimulation of secondary/transverse flows in the microchannel. The groove-based micromixers generate helical flows within the microchannel to augment the mixing performance. These micromixers are extensively studied with respect to *planar* geometric parameters such as groove width, groove spacing, channel height, etc. The effect of *groove shape* on mixing performance has not been systematically studied. Previous studies have focused on two or three different predefined groove shapes, typically involving slanted grooves, asymmetric herringbone grooves, and their variations. In this computational study, we analyze the effect of groove shape on micromixing performance and search for the optimal groove shape for a pressure-driven flow across the microchannel. The groove shape is parametrically represented by Bézier curves which could take any shape within a constrained plane. The control points of the Bézier curve are chosen as optimization parameters to identify the optimal groove shape which maximizes the mixing for given operating conditions. The optimization is carried out for pressure-driven flow with and without staggered arrangement of grooves. The resulting single groove optimal design improves the mixing efficiency from 0.18 for T-mixer to 0.85 for the same operating conditions (Re $\sim$0.42, Pe $\sim$4,200). Unlike previous studies, axial mixing index profiles are presented for different micromixers which clearly distinguish the effect of flow field on the mixing performance. Various parametric studies are carried out to compare the optimal groove structure with other common groove type (staggered, herringbone, etc.) micromixers for a range of Pe between 400 and 6,200. The improved mixing performance in optimal designs is due to a continuously growing finger-like structure of the interface which enhances the overall mass transfer.

Keywords Micromixing · Microfluidics · Optimization · Groove-mixer

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1 Introduction

Micromixers are a vital component of biomicrofluidics devices utilized for complex enzyme reactions (Atalay et al. 2009), biochemical analysis (Liu et al. 2008), bio-diagnostics, etc. Microfluidic or Lab-on-a-chip (LOC) devices offer significant benefits over their traditional laboratory counterparts in terms of device size, sample/reagent usage, and analysis time (Whitesides 2006; Chang 2006; Dittrich and Manz 2006). The performance of micromixers directly relates to the analysis time and portability of such devices. The micromixers can be categorized into active and passive mixers (Nguyen and Wu 2005) depending upon their mixing strategy. Active mixers utilize external energy—via pressure, electrokinetic disturbance, etc.—to induce transverse flows (which are a prerequisite for effective mixing). On the other hand, diffusion and chaotic advection are the dominant mixing mechanisms in passive mixers. The simplest passive micromixer is a T-mixer or Y-mixer, where two confluent streams mix primarily due to transverse diffusion. The mixing performance in passive mixers can be enhanced using geometric modifications such as obstacle-based micromixing (Chang and Yang 2004; Wu and Li 2008; Jain et al. 2009), heterogeneous charged walls/bottom (Biddiss et al. 2004; Chang and Yang 2006) for electrokinetic