Chemical Engineering Journal 217 (2013) 320–328

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Fluid mixing via multidirectional vortices in converging–diverging meandering microchannels with semi-elliptical side walls

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HIGHLIGHTS

- ▶ A converging–diverging meandering channel for efficient fluid mixing was proposed.
- ▶ The planar micromixer may generate multidirectional vortices to enhance mixing.
- ▶ The generation of vortices involves a large expansion ratio and a large curvature.
- ▶ The micromixer with smooth walls avoids unintentional effects on fragile specimens.
- ▶ Comparisons of the performance of several meander-channel micromixers were made.

ARTICLE INFO

Article history:
Received 10 May 2012
Received in revised form 29 November 2012
Accepted 3 December 2012
Available online 8 December 2012

Keywords:
Microfluidics
Mixing
Converging–diverging channel
Dean vortices
Separation vortex

ABSTRACT

An effective planar micromixer based on a meandering microchannel with converging–diverging cross section is proposed, fabricated and investigated in this work. The side walls of the microchannel consist of successive semi-elliptical surfaces with perpendicular major axes. The results of this work show that the fluid mixing in such a microchannel is enhanced by the multidirectional vortices, including the Dean vortices in the transverse plane due to centrifugal force in the meander-channel flow and the separation vortices caused by the converging–diverging cross section of the meandering channel for the case with a large flow rate and a small enough radius of curvature. We fabricate the micromixer by a single lithography process and the fluid mixing in the micromixer is observed by using a confocal spectral microscope imaging system. The fluid mixing is also simulated by a commercial code. The simulation results are in reasonable agreement with the experimental results. The results show that the mixing efficiency of the present micromixer with a large expansion ratio defined as the maximum width divided by the minimum width of the main channel is generally better than that of the ordinary meander-channel micromixer with constant cross section for the case with a large flow rate and a small radius of curvature. Besides, more simulation results show that the present meandering-channel micromixer formed by semi-elliptical side walls with perpendicular major axes is superior to the meandering-channel micromixer formed by semi-elliptical side walls with aligned major axes, the meandering-S micromixer and the Sigma micromixer.

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1. Introduction

Complete and rapid mixing is essential in many microfluidic systems applied in biochemistry analysis in the fields of the micro-total analysis systems (μTASs) [1–4] and in microreactors [5]. Since the flow is predominantly laminar in micromixers, the common mixing methods adopted are increasing the interfacial area or decreasing the diffusion path between the mixing fluids. On the whole, the micromixers can be classified into two types, active micromixers and passive micromixers [2–4]. Active micromixers rely on the moving parts or the external energy source, whereas passive micromixers rely on the features of microchannel geometries to achieve mixing. In general, active micromixers have a better mixing efficiency than passive micromixers. However, passive micromixers are widely utilized in the microfluidic systems, because it is simpler to fabricate them and easier to integrate them with microfluidic systems.

Various microchannel geometries have been proposed to enhance mixing in passive micromixers. Three-dimensional channel structures [6,7] are used to induce chaotic advection [8] which can enhance fluid mixing effectively. However, their fabrication process requires multi-step lithography process. In planar micromixers, the strategies developed to enhance mixing include

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http://dx.doi.org/10.1016/j.cej.2012.12.016