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Simulation and experimental investigation of planar micromixers with short-mixing-length

Mohammad Sadegh Cheri [a,b], Hamid Latifi [a,b,*], Mohammadreza Salehi Moghaddam [a], Hamidreza Shahraki [a]

[a] Shahid Beheshti University, Laser and Plasma Institute, 1983963113 Tehran, Iran
[b] Shahid Beheshti University, Department of Physics, 1983963113 Tehran, Iran

HIGHLIGHTS

- Numerical (40 simulations) and experimental analysis of eight planer micromixers.
- Finding, analysis, fabrication and characterization of optimum micromixer.
- The optimum micromixer has 0.89 mixing efficiency at the 1.18 mm from the origin.
- The study of the chamber and obstacle effect on the mixing efficiency and pressure drop.

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ABSTRACT

Mixing laminar flows in short lengths is an important issue in chemical, biochemical and medical reactions. This work presents a numerical and experimental investigation on planar micromixers for obtaining an optimum micromixer with short mixing length. The numerical investigation of eight planar micromixers with two different chambers and four obstacle geometries is carried out by using three dimensional (3D) Navier–Stokes equations at the range of 0.1–40 of the Reynolds (Re) number. In total, 40 simulations (eight micromixers at five Re numbers) were done and the optimum micromixer was obtained by the analysis of the simulation data. The optimum micromixer has 0.89 and 0.99 mixing efficiency at Re = 0.1 and 40 respectively at the short distance of 1.18 mm from the origin. In addition, the effect of the chamber and obstacle geometry on mixing efficiency and pressure drop at the range of 0.1–40 of Re have been investigated. The results show that the chamber geometry manifests itself at a low Re number and obstacle geometry is significant at a high Re for mixing efficiency and pressure drop. The optimum micromixer was fabricated, tested and compared with the simulation results and both of them show a similar behavior in the mixing process.

1. Introduction

The unique advantages of microfluidics systems such as fast analysis time, small samples consumption, high throughput, portability and reproducibility have led to the rapid development of Lab-On a Chip (LOC) and micrototal analysis systems (μTAS) [1–2].

In most chemical, biological and medical applications such as fast and homogenous chemical reactions (crystallization, extraction, polymerization and synthesis), DNA assay (separation, hybridization and sequencing), cell lysis, biological screening and medical drug delivery, the performance of LOC and (μTAS) are determined by mixing efficiency. Therefore, among microfluidics devices, micromixers are one of the most important microdevices in LOC and μTAS and have been developed to obtain rapid and efficient mixing of samples [3,4].

Due to laminar flow regime in microfluidics systems, the dominant mixing mechanism is molecular diffusion which is a very slow process (Fick's second law) [5]. Therefore, molecular diffusion increases the time and length of the mixing process which is not compatible with miniaturization in microfluidics systems. In order to overcome this limitation, one effective solution for enhancing the mixing performance is to increase the interfacial area between different liquids to reduce diffusion distance (Fick's first law). Different micromixers are presented in the literature and depending on the mixing mechanism they can be categorized as active and passive micromixers [6]. Active micromixers use external field or energy such as, electro and magneto hydrodynamic [7,8], ultrasonic [9], electrokinetic [10] dielectrophoretic, pressure and thermal

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* Corresponding author at: Shahid Beheshti University, Laser and Plasma Institute, 1983963113 Tehran, Iran. Tel.: +98 02129904254.
E-mail address: latifi@sbu.ac.ir (H. Latifi).

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distribution [11–13] to improve the mixing process. Although active micromixers have a good mixing performance at small distances, they have such drawbacks as high consumption of energy, complexity of structure and their being difficult to manufacture and integrate with other microfluidics components. On the other hand, passive micromixers do not need any external source and are usually fabricated and integrated more easily with LOC technology than are active micromixers [6]. Therefore, researchers prefer to design and optimize passive micromixers [14–16].

Lamination and chaotic advection are two main mechanisms which are employed in passive micromixers for enhancing the mixing process. In lamination mechanism, the fluid is split into several laminar fluids and then recombined in order to increase the interfacial area (increasing the molecular diffusion) between the fluids [17,18]. Branebjerg et al. [19] have presented the first Split and Recombine (SAR) micromixer using this concept. In chaotic mechanism, the mixing is based on the creation of the transverse motion of flow with stretching, folding and breaking up the fluid in the cross-section of the channel. Chaotic mechanism can be achieved by different shapes of the channel. Hossain et al. [20] have evaluated the mixing performance in three channel designs including zigzag, square-wave and curved. Stroock et al. [21] have used staggered herringbone patterns on the surface of the channel to achieve an efficient mixing. Embedded obstacle inside the microchannel is another chaotic mechanism for enhancing the mixing process. Fang et al. [22] have presented a chaotic micromixer with oblique barriers on the microchannel's walls and have investigated the period of the mixing unit, as a crucial parameter in improving mixing. They have achieved a good mixing after 28-period mixing unit. Wang et al. [23] have optimized the layout of obstacles in microchannels in order to enhance mixing. Chung et al. [24] have designed a simple planar baffled micromixer with a short mixing distance for synthesis of nanoparticles.

In this paper, the mixing performance and pressure drop of eight micromixers, with the combination of two different chambers and four different obstacles are investigated for the purpose of comparing mixing performance and pressure drop in order to obtain an optimum design. An optimized design is selected and fabricated by a soft lithography method and is compared with the experimental results. Section 2 considers the design and simulation results of eight planar micromixers and in Section 3 the fabrication and test of the optimum design micromixer is presented and compared with the simulation results.

2. Micromixer design and numerical investigation

2.1. Micromixer design

Figs. 1a,b and 2 show the design of planar micromixers with two different chambers including Round Corner Rectangular (RCR), Hexagonal (H) and four different obstacles with shapes including Straight (S), Chevron (Ch), Arc (A) and "Check Mark" (CM) respectively. Eight micromixers with the combination of two different chambers and four obstacles are designed. For simplicity, we name the eight micromixers with two word phrases separated by a hyphen where the first and the second terms refer to the chamber and obstacle name respectively. Therefore, the eight micromixers are (1) Hexagonal–Chevron (H–Ch), (2) Hexagonal–Check Mark (H–CM), (3) Hexagonal–Arc (H–A), (4) Hexagonal–Straight (H–S) (5) Round Corner Rectangular–Chevron (RCR–Ch), (6) Round Corner Rectangular–Check Mark (RCR–CM), (7) Round Corner Rectangular–Arc (RCR–A), and (8) Round Corner Rectangular–Straight (RCR–S). The reference origin is located at the center of the confluence in the middle of the two inlet channels and the system of coordinates (X, Y, Z) is defined by X as the stream wise direction of the outlet channel; Y as the direction normal to X in the plane of the inlet channels and Z as the height of the micromixer. The dimensions of obstacle and chamber geometry are shown in Table 1.

In all micromixers, the height (z) and width of obstacle dimensions are 40 and 50 μm respectively. Also $2Wa = W_b$, $2W_a + W_b = W_c$ and the sum of $W_1 + W_2 = W_3 + W_4 = 120$ μm is constant.

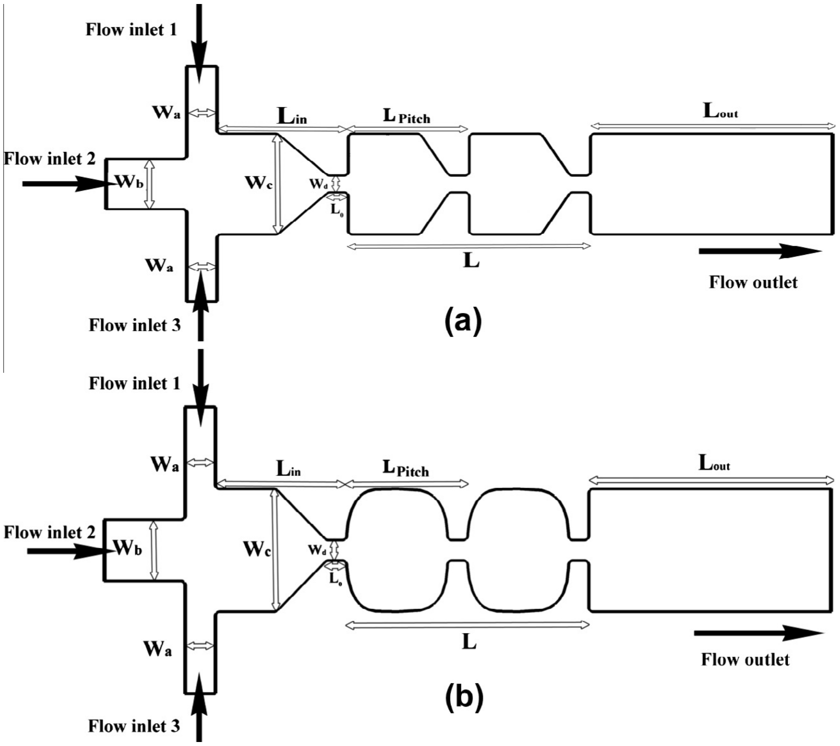

Fig. 1. The design of planar micromixer (a) Hexagonal chamber (H) and (b) Round Corner Rectangular chamber (RCR).