*Sensors & Transducers, Vol. 182, Issue 11, November 2014, pp. 49-52*

**Sensors & Transducers**

*http://www.sensorsportal.com*

# Design and Simulation for a Two-dimensional Rectangle-Square Wave Micromixer

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*Received: 10 May 2014 /Accepted: 30 October 2014 /Published: 30 November 2014*

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**Abstract:** An effective two-dimensional micromixer named rectangle-square wave micromixer with very simple structure has been presented. The rectangle-square wave micromixer based on split and recombination principle was simulated to analyze the fluid flow and the mixing efficiency. The flow rate, sample concentration, pressure drop at different position in the micromixer was researched. The simulation results show the micromixer can appear good performance for a wide range of flow rates with smaller pressure drop. The rectangle-square wave micromixer is proven to be effective and will have great potential to be integrated to other microfluidic systems. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Rectangle-square wave micromixer, Mixing efficiency, Flow rate, Pressure drop, Simulation.

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## 1. Introduction

Mixing process is an essential issue in the microfluidic systems. Many types of micromixers have been developed which can generally be classified into two categories: active micromixers and passive micromixers [1]. Active micromixers always need a continuous connection to an external power supply [2]. Their design and fabrication are also complicated [3]. Hence, passive micromixers have attracted more and more attention. Jung et al. reported an integrated microdevice consisting of an efficient passive mixer, a magnetic separation chamber, and a capillary electrophoretic microchannel in which DNA barcode assay, target pathogen separation, and barcode DNA capillary electrophoretic analysis were performed sequentially within 30 min for multiplex [4]. A novel passive micromixer concept is presented. The working principle is to make a controlled 90° rotation of a flow cross-section followed by a split into several channels; the flow in each of these channels is rotated a further 90° before a recombination doubles the interfacial area between the two fluids. This process is repeated until achieving the desired degree of mixing [5]. Ansari et al. designed and fabricated a new passive micromixer based on the concept of unbalanced splits and cross-collisions of fluid streams. The micromixer shows interesting mixing behavior for different ratios of the widths of the two split sub-channels, and the results show the lowest mixing performance for the case of uniform width, where balanced collisions occur [6]. A two dimensional model of hexagonal passive micromixer is analyzed with surface roughness present on inner walls of channels using parallel Lattice Boltzmann method, implemented on sixteen node cluster [7]. Loc, *et al.* presented a passive micromixer with staggered herringbone structures was used for luminol-peroxide chemiluminescence detection. The micromixer was examined to assess its suitability for chemiluminescence reaction [8]. Papadopoulosa, *et al.* demonstrated a passive micromixer with zigzag geometry to perform simultaneously mixing of a restriction enzyme with DNA and digestion of DNA [9]. Liu, *et al.* presented a novel efficient passive micromixer, and the detailed layout of passive micromixers was obtained by solving a variational optimization problem, in which the manufacturability and periodicity of passive micromixers can be considered by adding the corresponding design constraints [10]. A passive micromixer integrated with a microfluidic chip was presented for calcium assay based on the arsenazo III method. The ability for low reagent consumption and minimum waste production in a miniaturized system has generated great interest in the green chemistry field [11]. Kuo, *et al.* presented a passive micromixer on a compact disk microfluidic platform that performs plasma mixing function. The results show that given an appropriate specification of the microchannel geometry and a compact disk rotation speed of 2000 rpm, a mixing efficiency of more than 93 % can be obtained within 5 s [12].

In this research, we present an effective micromixer, which is named rectangle-square wave micromixer. The rectangle-square wave micromixer is based on split and recombination theory. Simulation was executed to study the fluid flow and the mixing efficiency for the micromixer. The simulation results show the micromixer can express a high performance with the very simple structure.

## 2. Design and Simulation

### 2.1. Governing Equations

The flow of an incompressible newtonian liquid in microchannels can be described by the navier-stokes equation and continuity equation as shown in Eqs. 1, 2 respectively:

$$\rho\cdot\frac{\partial \boldsymbol{u}}{\partial t}+(\boldsymbol{u}\cdot\nabla)\boldsymbol{u}=\boldsymbol{f}-\nabla p+\mu\nabla^2\boldsymbol{u}, \tag{1}$$

$$\nabla\cdot\boldsymbol{u}=0\,, \tag{2}$$

where $\boldsymbol{u}$ is the velocity vector, $\boldsymbol{f}$ is the body force, $\rho$ is the density of the fluid, $p$ is the pressure, $t$ the time, and $\mu$ is the dynamic viscosity of the fluid.

The basic phenomenology of mixing is described by means of the convection-diffusion equation for the concentration distribution in the fluid system, as follows:

$$\frac{\partial c}{\partial t}+(\boldsymbol{u}\cdot\nabla)c=D\nabla^2 c \tag{3}$$

where $c$ is the species concentration and $D$ is the diffusion coefficient.

### 2.2. Simulation

In this section, the numerical simulation was executed to research the performance of the rectangle-square wave micromixer. The COMSOL Multiphysics was used to solve incompressible navier–stokes equation and convection-diffusion equation. The free mesh elements that can easily adapt to the structure of the channel were chose. The tetrahedral free meshing method, with a maximum element size scaling factor at 0.18, an element growth rate at 1.12, a mesh curvature factor at 0.25, was used in the simulation.

The inlet flows were set as laminar flows. The boundary conditions were set as follows: the flow velocity at channel walls as zero, and species concentrations at inlets followed normal distribution centered at zero. Other parameters used in the simulation included 20-100 μm/s for the average linear velocity of fluids at inlets, 10−12 mm$^2$/s for the diffusion coefficient for the solute in the solvent, 1000 kg/m$^3$ for the fluid density and 10$^{-3}$ Pa·s for the kinetic viscosity.

### 2.3. Micromixer

The external channel dimension of the rectangle-square wave micromixer was very small with the length 480 μm and the width 100 μm. The micromixer was alternately composed of two rectangle channels and two square wave channels. There are two inlets and one outlet on the micromixer. Two different concentration samples will be injected the micromixer from Inlet 1 and Inlet 2, respectively, and the mixed sample will outflow from Outlet. The entrance and export of the first rectangle channel was named a and b, and the entrance and export of the second rectangle channel was named c and d, respectively. The width of the channels micromixer is 20 μm. The schematic diagram of the rectangle-square wave micromixer is shown in Fig. 1.

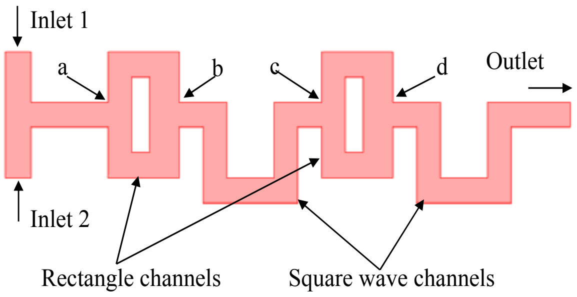

**Fig. 1.** Schematic diagram of the rectangle-square wave micromixer.

## 3. Results and Discussion

### 3.1. Mixing Efficiency with Different Flow Rates

Flow rate is critical to finish physical, chemical and biochemical functions. Some mixing and reacting researches usually need to be executed a wide range of flow rates. In this section, the mixing efficiency of the sample was studied with the flow rates from 20 μm/s to100 μm/s, as shown in Fig. 2.

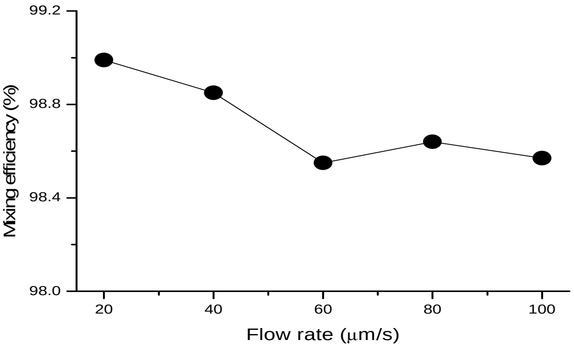

**Fig. 2.** Mixing efficiency of the sample with the different flow rates.

From the simulation results, the mixing efficiencies were more than 98 % for all the flow rates. So, the rectangle-square wave micromixer is effective to finish two different samples mixing.

### 3.2. Pressure Drop with Different Flow Rates

For some sample mixing, the stability of the fluid flow is essential. Pressure drop is an important monitoring indicator to ensure flow stability. The pressure drop between inlet of the micromixer and entrances of the rectangle channels, inlet of the micromixer and exports of the rectangle channels, inlet and outlet of the micromixer were solved, respectively. Fig. 3 shows the pressure drop sequentially with the flow rate 100 μm/s. 1 represents the pressure drop from inlet to a, 2 from inlet to b, 3 from inlet to c, 4 from inlet to d, and 5 from inlet to outlet.

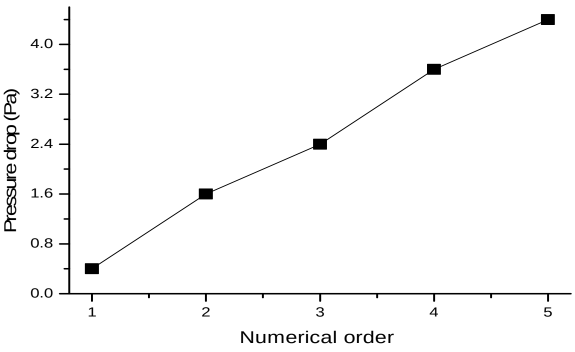

**Fig. 3.** Pressure drop between different positions.

It can be obtained from Fig. 3, the maximum pressure drop was 4.4 Pa, which happened between inlet and outlet of the micromixer. The pressure variance was uniform, and the stability of the micromixer was well.

### 3.3. Concentration Distribution of the Sample

To show the performance of the micromixer, two samples with the concentration 1 mol/L and 0 mol/L were injected into the micromixer from Inlet 1 and Inlet 2, respectively. Fig. 4 shows the concentration distribution of the sample with the flow rate 100 μm/s.

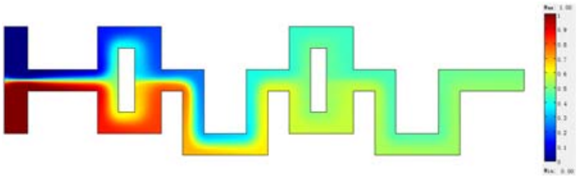

**Fig. 4.** The concentration distribution of the sample with the flow rate 100 μm/s.

## 4. Conclusions

A two-dimensional rectangle-square wave micromixer with alternately combination of two rectangle channels and two square wave channels has been presented. The micromixer has very simple structure and good performance. The mixing efficiency was cover 98 % with the flow rate from 20 μm/s to 100 μm/s. The variance of the pressure drop was uniform, and the maximum pressure drop was 4.4 Pa in the micromixer. The rectangle-square wave micromixer is proven to be effective and can simply be integrated to other microfluidic devices.

## Acknowledgements

This work was supported by National Natural Science Foundation of China (51405214), Liaoning Province Doctor Startup Fund (20141131), Fund of Liaoning Province Education Administration (L2014241), and the Fund in Liaoning University of Technology (X201301).

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