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Design and Analysis of Micro-Mixer for Enhancing Mixing Performance

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Abstract
Design and analysis of various micro-mixers for enhancing the mixing performance is presented in this. The shape of micro channels is an important design variable to achieve the desired mixing performance. However, if obstacles and wavy channels are included into the channel design, mixing improves. Micro-mixer with obstacles located at the centre of the channel with different configurations is used to enhance mixing performance, so as to reduce the mixing length. Different shapes of obstacles such as rectangle, square and rhombus are analyzed by comparing it with plain Y shape circular chamber mixer. For the same boundary conditions, the rectangular obstacles at the centre of the chamber, generally gives minimum mixing length.
Keywords: *Micro-mixer, Y channel, Mixing Performance, COMSOL Multiphysics.*

1. Introduction

Mixing is an important process in a microfluidic system such as micro total analysis systems. The aim of microfluidic mixing is to achieve a thorough and rapid mixing of multiple samples in micro scale devices [1]. Generally micromixer can be categories into two: Passive and Active, Each of these micromixers is differentiated by their capacity, mixing speed and operating requirements. For example, an active micromixer requires external power source in order to effect mixing in the device while a passive micromixer achieves mixing with increasing contact area and contact time [2]. The term 'mixing' means a physical process where both the stirring and the diffusion occur simultaneously. Here, the word stirring means the advection of material blobs subjected to mixing without diffusive action. In other words, we can say that good mixing of low diffusivity materials occurs in two stages; stirring in the first stage and diffusion in the second stage [3]. These mixers are differentiated by the hydrodynamic principle employed. The four important principles employed are Hydrodynamic focusing, Flow separation, chaotic advection and Split and recombine flows.

Table 1: Summary of various principles for micro mixing and their overall rank for use in microfluidic devices as a mixer.

Means of mixing	Chaotic Advection	Fabrication Cost	Overall Rank
Hydrodynamic focusing	No	High	4
Alternate injection	No	Moderate	3
Geometry effect	Yes	Moderate	2
Electrokinetic method	Yes	High	3
Droplet mixing	Yes	Low	1
Stirring by particles	-	High	4

1. 2. Theoretical Analysis of Micromixer

The variables that affects for the mixing are the flow rate corresponding to Re and the channel cross-sectional area. The mixing between the two fluids takes place mainly in the narrow channel after they collided with the obstacle producing the turbulence[4].For that two characteristic dimensionless numbers such as Reynolds number (Re) and the Peclet number (Pe) are essential, in order to determine the effective operation condition of a passive micromixer.

Re is defined as,

$$\mathbf{Re} = \frac{\boldsymbol{\rho\vartheta d}}{\boldsymbol{\mu}} \qquad (1)$$

Where Re represents the ratio between momentum and viscous friction and μ, ρ, v, and d indicate the dynamic viscosity, fluid density, fluid velocity, and characteristic dimension.

Pe is defined as

$$\mathbf{Pe} = \frac{\mathbf{vd}}{\mathbf{D}} \qquad (2)$$

Where, Pe represents the ratio between the mass transport due to convection and diffusion.

The transverse diffusion time can be estimated by the following equation,

$$\mathbf{t} = \frac{\mathbf{d}^2}{\mathbf{D}} \qquad (3)$$

Where d is the channel width and D is the diffusion coefficient.

Therefore, the characteristic mixing length (L) of the micromixer to achieve complete mixing is

$$\mathbf{L} = \boldsymbol{\vartheta}\mathbf{t} = \boldsymbol{\vartheta}\frac{\mathbf{d}^2}{\mathbf{D}} = \mathbf{Pe.d} \qquad (4)$$

In the microfluidic channel, L is in centimetre. Therefore Eq. (4) indicates that, a higher Pe number lowers the mixing by diffusion due to the limited L value. Therefore, if the Re value is lower than a critical value for turbulent flow or if it is ineffective to induce vortex formation, the higher Re value makes the mixing less efficient. The Re critical value depends on the flow velocity and the mixer structure [4].

3. Design and Analysis

All The basic design for a micro-mixer is represented by Y shaped channel. The mixing process in this type of micromixer is obtained by guiding the two liquids, to be mixed in a flow channel. Mixing for Y shaped micromixers is solely depends on diffusion of the species at the interface between the two liquids, hence the mixing is rather slow and a long mixing channel is required.

3.1 Geometry of Channel:

The Geometries affect on fluid mixing that will enhance advection in the mixing of fluids. If a single straight channel is used the fluid will tend to stay very laminar and have no advective mixing. However if obstacles and wavy channels are integrated into the channel design, mixing improves.

3.2 Specification of Problem:

The sample fluids used in the simulation were water and Benzoic Acid. The molar concentration of one of the fluid species was set to 0 and other to 20. As mixing takes place, the molar intensity on one side of the channel decreases from 20, while on the other side it increases from 0. Near about Complete mixing was achieved when the molar intensity of the two fluids reached to10±0.5 mol/m^3.

Table 2: Boundary Conditions For Simulation

Channel Inlet 1	Velocity Inlet	0.1 mm/s
Channel Inlet 2	Velocity Inlet	0.1 mm/s
Channel Outlet	Pressure Outlet	1 atm pressure
Channel Bottom	Wall	No slip
Channel Left	Wall	No slip
Channel Right	Wall	No slip
Channel top	Wall	No slip
Channel Inlet 1	Velocity Inlet	0.1 mm/s

3.3 Meshing of Geometry:

Structured meshing method is used for meshing the geometry with extremely coarse mesh.

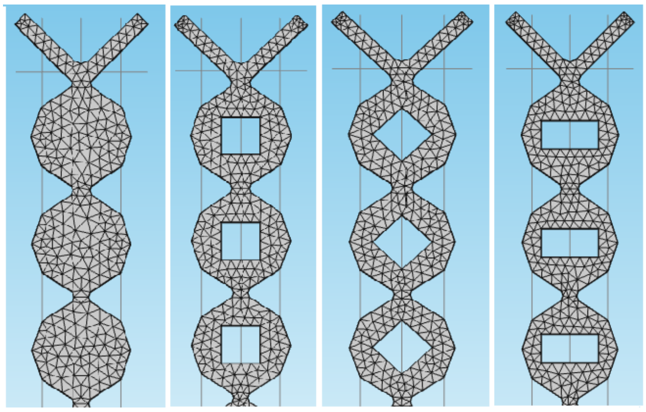

Figure 1: Mesh of Y Shape Circular Chamber Micromixers

A] Without any obstacle B] Square obstacle
C] Rhombus obstacle D] Rectangular obstacle

4. Simulation Results

Figure 2 shows mixing length and mixing behaviour in circular Y shape micro-mixer. It has been observed that mixing takes place at 60mm, 48mm, 41mm, 55mm distance.

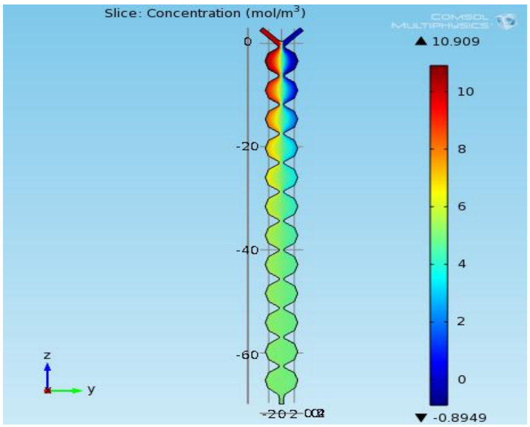

Figure 2 a) Simulation Result - without any obstacle

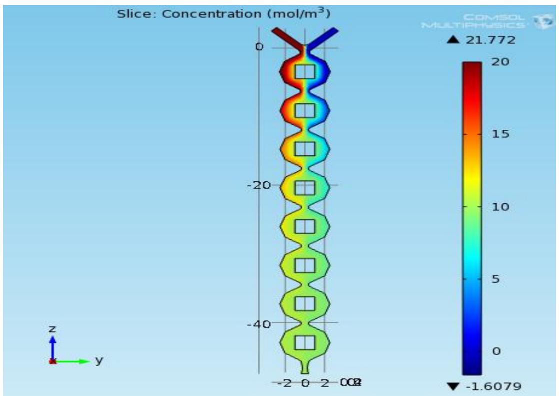

Figure 2 b) Simulation Result - With Square obstacle

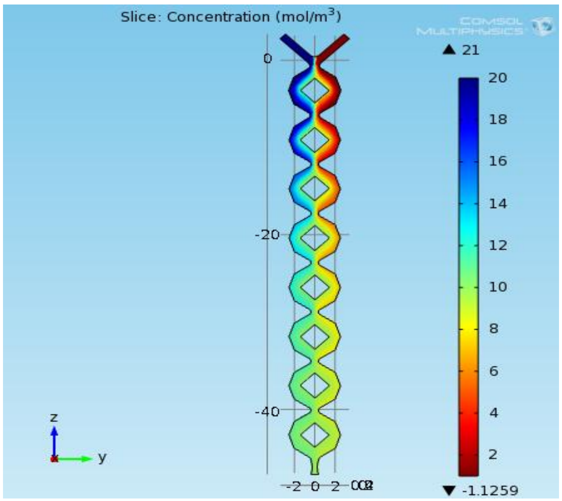

Figure 2 c) Simulation Result - With Rhombus obstacle

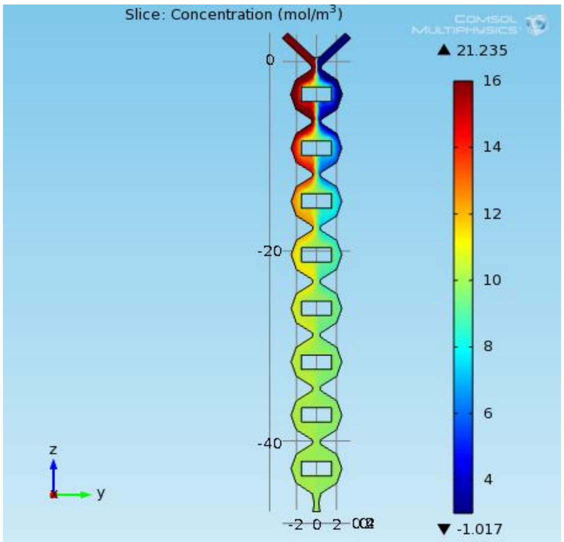

Figure 2 d) Simulation Result - With Rectangular obstacle

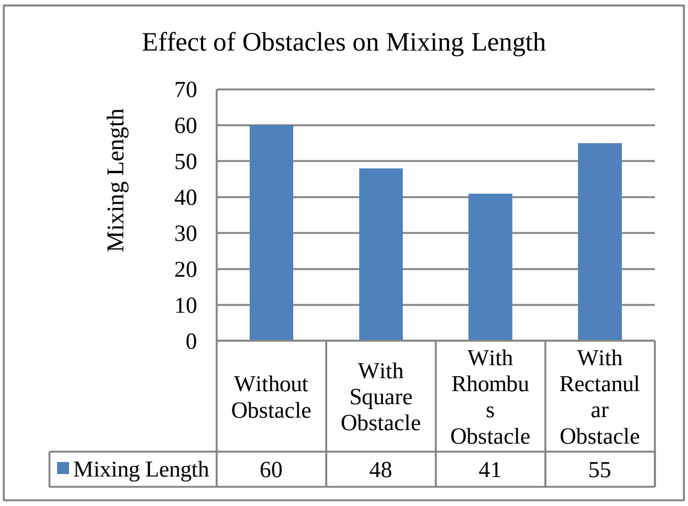

Figure 3: Mixing length vs different configurated obstacles in circular Y shape Micromixer

5. Fabrication of Micro-mixer:

The AutoCAD drawing of Y shape circular chamber channel is printed on a transparency sheet which is called mask at a resolution of 12000 dpi.

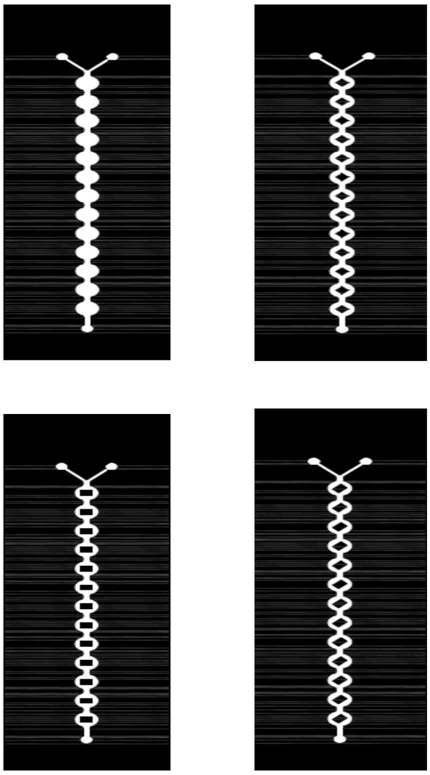

Figure 4: Mask used for Circular Y shape Micromixer

Steps require to carry out Photochemical Machining and PDMS Mould making are shown in following flow charts A and B respectively.

Cleaning of metal Substrate:

↓

Coating of a negative photoresist LPR on substrate

↓

Exposed substrate to UV source for about 2 min.

↓

Developed in developer solution for 1 min.

↓

Etching of substrate is done using $FeCl_3$solutiontion for 1 min.

Flow chart A: Photochemical Machining Process

Pour the required amount of curing agent and PDMS base in 1:10 ratio

↓

Whisk this mixture vigorously with a spatula about 10 mins

↓

Kept in a desiccator to make the trapped air bubbles escape

↓

Spin it over the molds.

↓

For curing place the PDMS with mold on a hotplate at 150°C for about 6-8 mins.

↓

After cooling, Peel off PDMS with holder

Flow chart B: PDMS Mould Making

6. CONCLUSION

Mixing length in the channel generally depends upon diffusion coefficient, width and height of the channel, inlet velocities of the fluids, viscosity of fluids and geometric layout of micro-mixer. As the width of channel increases, the mixing length of micro-mixer channel is increases. Increase in diffusion coefficient leads to decrease in mixing length of micro-mixer channel. Decreasing the inlet velocities of the incoming fluids, decreasing the mixing length of micro-mixer channel. Different obstacles like rectangular, square and rhombus when placed at the centre of the channel also affect the mixing length of the channel. The shape and size of the obstacles also affecting the mixing length. For the same boundary conditions, the rectangular obstacles placed on the wall of the channel, generally gives minimum mixing length.

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