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DESIGN AND ANALYSIS OF Y SHAPE WAVEFORM MICRO-MIXERS FOR DIFFERENT SPACING BETWEEN MICRO-CHANNEL

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Abstract: In general, macro-scale mixing is achieved with turbulence while mixing in micro-scale relies mainly on diffusion. This is due to the laminar behavior of the flow in micro channels with characteristics low Reynolds number. In this paper, Comsol multyphysics, a commercial CFD tool, is used to study the mixing of two liquids in Y shape waveform micro-mixer. Analytical as well as simulation results of normal Y shape micro-mixer is compared. Analysis of Y shape waveform micro-mixer with spacing between channels is studied. Micro-channel with less spacing i.e. 1w gave minimum mixing length in Y shape waveform micro-mixer.

Keywords: Micro-fluidics, diffusion mixing, micro-flow, micro-mixer, waveform micro-channel, CFD.

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INTRODUCTION

Micro fluidics is the study of fluid flow in geometries having one of the dimensions being of the micrometer scale. In any lab-on-a chip (LOC) system, mixing is an important micro reaction, which is required for fast and homogenous on-chip mixing of samples and reagents. Due to the laminar nature of flow in micro-channels, majority of micro mixers are based on diffusion mixing.

NOMENCLATURE

D Diffusion Coefficient (mm^2/s)

c Molar concentration (mol/m^3)

T Absolute temperature in (˚C)

L_m Length of channel for complete mixing (mm)

P Pressure (Pa)

R Gas constant

t Mixing time (s)

V mean velocity (mm/s)

w Width of channel (mm)

µ Dynamic viscosity (Pa.s)

φ Diffusion flux

H Variable height

Lee et al. [1] presented a review of operational principles and mixing performance of active or passive micro-mixers depending on their mode of operation. Lorenzo et al. [2] presented review of the characteristics of fluidic behavior at the micro-scale and their implications in micro-fluidic mixing processes. Naher et al. [3] investigated flow characteristics and mixing efficiency of different geometries in micro-channels with obstacle and without obstacle to visualize the fluid flow path.

Wang et al. [4] studied the mixing performance of the Y-channel mixers. The use of obstacles inside channel was investigated to improve the performance of Y-shape. Asgar et al. [5] presented design, simulation, fabrication and characterization of a planar passive micro-fluidic mixer capable of mixing at low Reynolds numbers. A effect of the diamond-shaped obstruction geometry and its location in the channel on mixing was analyzed using the CFD-ACE+ software to optimize micro mixer performance. Chen et al. [6] established a macro-micro-model for the E shape micro mixer to analyze the flow field in a straight micro-channel and a curved micro-channel. The macro-model was presented based on a convection-diffusion equation and was used to analyze the variation of concentration in a straight channel. Heeren et al. [7] studied an array of micro fluidic channels and established the experimental setup for determining the diffusion constant. Tijjani et al. [8] performed the numerical and experimental analysis of capillary effect for driving a fluid within micro-channel.

II. INTRODUCTION TO MICRO-MIXING

In biomedical and chemical analysis, two solutions are generally mixed to make a reaction possible. In macro-scale, mixing is achieved with turbulence, while in micro-scale mixing process relies mainly on diffusion due to the laminar behavior of the flow with low Reynolds number. The mixing rate is determined by the flux of diffusion. Fig.1 depicts the range of diffusion coefficients of different materials.

$$\varphi = -D\frac{\partial c}{\partial x} \quad (1)$$

Where, D = diffusion coefficient in m^2/sec and C = is the species concentration in kg/m^3.

$$D = \frac{RT}{fN_A} \quad (2)$$

Where, R = gas constant, T = absolute temperature, N_A = Avogadro number = 6.02×10^{23} and f = Friction factor that is proportional to the viscosity μ. At a constant temperature, D is inversely proportional to μ:

$$D = \frac{C_D}{\mu} \quad (3)$$

Where, C_D = constant incorporating all other factors.

With a constant flux, Φ the mass transport by diffusion is proportional to the contact surface of the two mixed species. The average diffusion time, t over a relevant mixing path, w *is* given as

$$t = \frac{w^2}{D} \quad (4)$$

Equation (4) shows that the diffusion time or the mixing time is proportional to the square of the mixing path. Due to their small sizes, micro-mixers decrease the diffusion time significantly i.e. fast mixing can be achieved with smaller mixing path and larger contact surface.

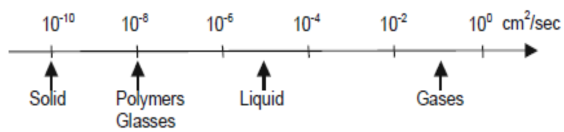

Figure 1 Diffusion Coefficient Range [5]

III. MATHEMATICAL MODEL

The most basic design for a micro-mixer is a Y shaped channel micro-mixers. The mixing process in this type of micro-mixer is obtained by guiding two liquids to be mixed through the upper limbs of "Y" channel. In a basic design of a Y type micro-mixer, mixing only depends on diffusion of the species at the interface between the two liquids, and hence the mixing is quite slow and a long mixing channel is required. In order to enhance the mixing efficiency, different shapes were added.

The mixing process in Y Shape Waveform Micro-Mixers are obtained by guiding the two liquids to be mixed in contact through a flow-through channel. It observed that, for the basic design of T and Y type micro-mixer, mixing 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. In order to minimize the mixing length, different modifications to the geometrical setup by converting straight channel into rectangular waveform channel shown in figure 1. The geometry of the micro-mixer consists of two inlet channels, each with a width of 0.2 mm and a depth of 0.2 mm. The angle between two inlet of Y shape channel is $60^{0.}$ For a reduction of the computational domain, shortened inlet channels of length 1mm are used. The geometry of Y-shape waveform micro-mixer is draw in area A (5 mm x H mm) where H is variable height from the junction. In this study, spacing between each waveform channel is varied by 1w, 2w, 3w and 4w where w is cross-sectional width of both channel. The dimensions of waveform channels are same as the inlet channels. The sample fluids used in the simulation were water and Benzoic Acid whose diffusion coefficient is 1x 10^{-10} m^2/s. The inlet velocity of 1 mm/s was assumed to be uniform and constant across the inlet cross-section. The fluid exhausts into the ambient atmosphere which is at a pressure of 1 atm and no-slip boundary conditions are used at fixed walls. The molar concentration of one of the fluid species was set to 0 and the other to 20 to define the mixing length. 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±0.5mol/m^3.

The fluids are assumed to be Newtonian and incompressible; hence the Navier–Stokes and continuity equations can be considered as governing equations given below

$$(\vec{V}.\nabla)\vec{V} = -\frac{1}{\rho} + \gamma\nabla^2\vec{V} \qquad (5)$$

$$\nabla.\vec{V} = 0$$

$\vec{V}\vec{V}$ The evolution of the concentration is computed from the advection diffusion equation.

$$(\vec{V}.\nabla)c = D\nabla^2 c \qquad (6)$$

Where, D is the diffusion constant and c is the local concentration or mass fraction of a given species. The properties of the fluid assumed for simulation are as shown below.

Fluids	Viscosity (Pa.S)	Diffusion Coefficient (m^2/s)	Density in (Kg/m^3)
Water	0.001	1x 10^{-10}	1000
Benzoic Acid	0.00126	1x 10^{-10}	500

The above said governing equations are solved using the computational fluid dynamics software. Structured meshing method is used for meshing the geometry. An extremely coarse mesh is used for meshing the 3D geometry of Y shape waveform micro-mixer with different spacing between channel.

The simulation is done with the assumption of following boundary conditions.

Channel Inlet 1	Velocity at Inlet	1 mm/s
Channel Inlet 2	Velocity at Inlet	1 mm/s
Channel Outlet	Pressure at Outlet	atm. pressure

Channel Bottom	Wall	No slip
Channel Left	Wall	No slip
Channel Right	Wall	No slip
Channel top	Wall	No slip

The different configurations of channels used for the simulations with the details are as shown below

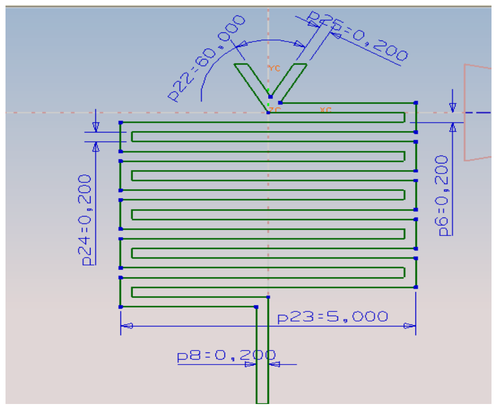

Figure 1 Y shape waveform micro-mixer with1w spacing between micro-channel

IV. RESULTS AND DISCUSSIONS

The simulation results of the above shown channels are as shown in figures below.

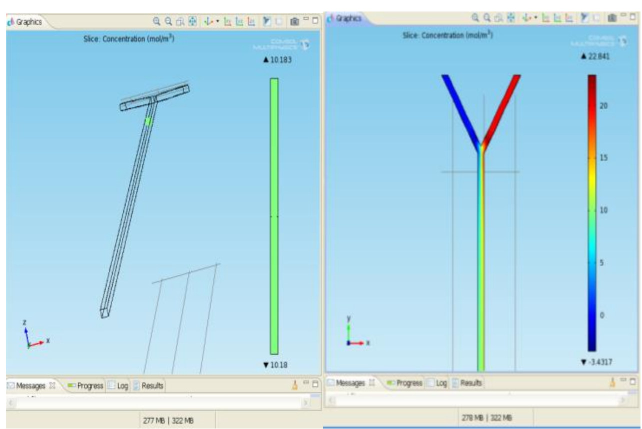

Figure 2 Simulation of Normal Y shape Micro-mixer

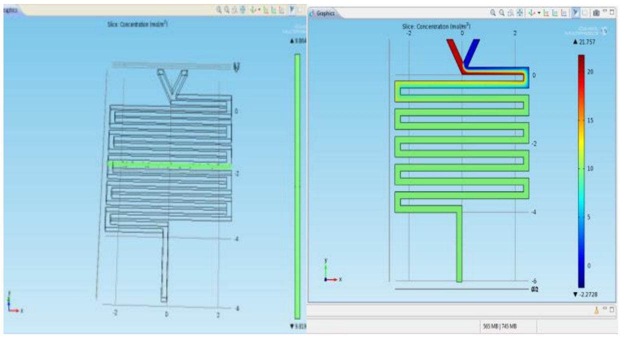

Figure 3 Simulation of Y shape waveform Micro-mixer with1w spacing between micro-channel

Table I Analysis of Mixing length

Sr. No.	Square waveform Channel Description	Input Avg. Velocity $V_{avg.}$ in mm/s	Mixing Length by Simulation in mm
1	Normal Y channel	1	40
2	Y channel with 1w spacing	1	24.5
3	Y channel with 2w spacing	1	29
4	Y channel with 3w spacing	1	33
5	Y channel with 4w spacing	1	35

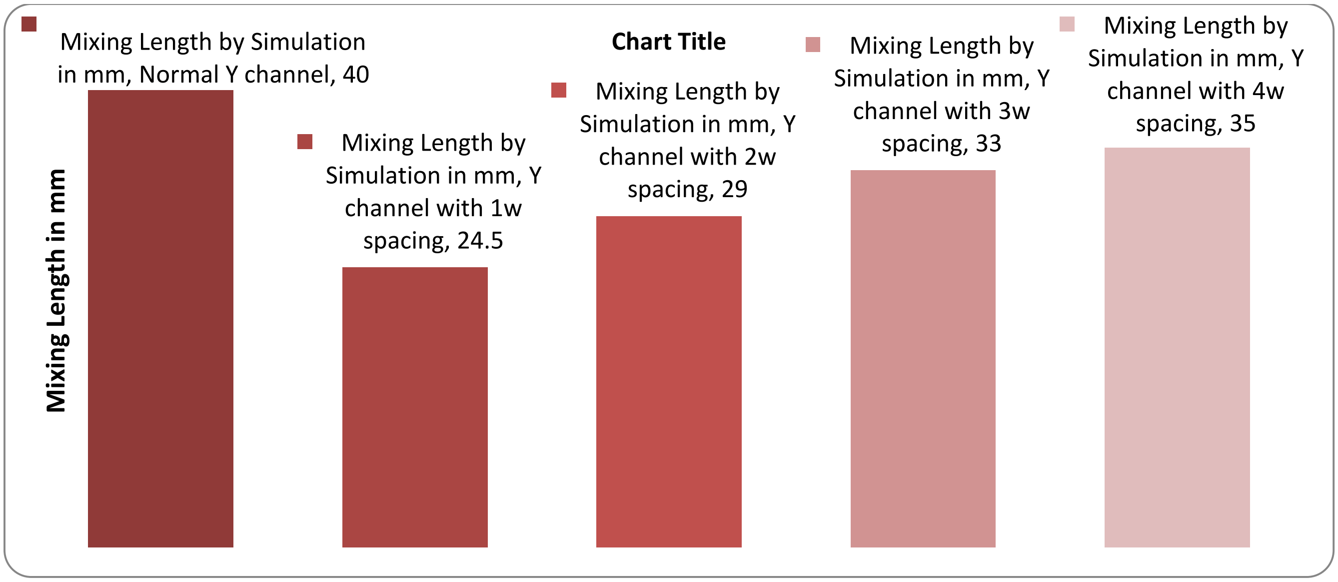

Figure 4 Comparision of Mixing length

The simulation results shows that the mixing length is minimum for the Y shape waveform micro-mixer having 1w spacing between micro-channel when compared to other types of Y shape waveform micro-mixer with different spacing. This may be due to the sharp corner and change in path introduce eddies in the flow pattern, which means maximum disturbance to the flow pattern and correspondingly better mixing leading to minimum mixing length.

V. CONCLUSIONS

Analytical and simulation mixing length were approximately same for normal Y shape micro-mixer. Simulations on the fluid flow in full scale Y shape waveform micro-mixer were performed in this study. To improve the mixing performance of Y shape micro-mixer, the use of waveform with different spacing i.e. 1w, 2w and 3w were investigated. The effects of waveform with different spacing between channel were studied for their effect on the mixing length in the channel. Based on the above simulated results, the following conclusions can be made:

1. With viscosity dominating flow in micro channels, mixing of two fluid streams mainly depends on diffusion.

2. The results demonstrated that spacing 'w' between channel can improve mixing performance by affecting the flow pattern.

3. The simulation results illustrate that mixing is enhanced as the spacing between channel decreases, the mixing length also decreases.

4. Minimum mixing length was observed for the Y shape waveform micro-mixer with 1w spacing between the micro-channels.

Further work is needed to investigate how obstacles affect the diffusion coefficient in the Sherwood equation.

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