Design and Analysis of Y Shaped Micro-Mixer with Different Configuration of Obstacles

Anil Shinde
Department of Mechanical Engineering, SVERI's College of Engineering,
Faculty Member
*E-mail:*anil.04.shinde@gmail.com

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" channel. Obstacles located on the channel wall are used to enhance mixing in the channel, so as to reduce the mixing length. Micro channels with different geometric layout and with different shapes and sizes of obstacles such as rectangular, triangular and semicircular, are analyzed for their mixing length. The triangular obstacles within the "Y" channel gave minimum mixing length for the same distance between the obstacles.

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

NOMENCLATURE

D diffusion Coefficient (mm^2/s)
c molar concentration (mol/m^3)
T Absolute temperature in (˚C)
Lm 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

I. INTRODUCTION

Micro fluidics is the study of fluid flow in geometries with 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

Wang et al. [1] 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. [2] 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. [3] 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. [4] studied an array of micro fluidic channels and established the experimental setup for determining the diffusion constant. Tijjani et al. [5] performed the numerical and experimental analysis of capillary effect for driving a fluid within micro-channel. Naher et al. [6] investigated flow characteristics and mixing efficiency of different geometries in micro-channels with obstacle and without obstacle to visualize the fluid flow path. Lorenzo et al. [7] presented review of the characteristics of fluidic behavior at the micro-scale and their implications in micro-fluidic mixing processes. Lee et al. [8] presented a review of operational principles and mixing performance of active or passive micro-mixers depending on their mode of operation.

.

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.

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

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

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

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:

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

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

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

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.

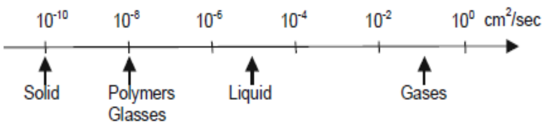

Figure 1 Diffusion Coefficient Range [2]

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 shaped obstacles were added on the channel wall like triangular, semicircular and rectangular.

The “Y” micro-mixer consists of two inlet channels, each with a width of 0.1 mm and a depth of 0.1 mm. The angle between two inlets is 60^0. The length of mixer channel from the junction is 50 mm long with the same width and depth as the inlet channels. In this basic “Y” channel, obstacles of different shapes and sizes are located on the walls. The distance between obstacles is maintained as 1 mm, 2 mm and 3 mm respectively for each type of obstacle, so that their performance can be compared with each other.

In case of triangular obstacle, the base length and height of triangular obstacle is kept 0.1 mm and 0.05 mm respectively. For semicircular obstacles, the diameter of semicircle is kept as 0.1 mm. for rectangular obstacles, the width and height of rectangular obstacle is kept as 0.1 mm and 0.05 mm respectively.

The sample fluids used in the simulation are water and Benzoic Acid, whose diffusion coefficient is 1x 10^{-10} m^2/s. The inlet velocity is assumed to be uniform and constant across the inlet cross-section and its value is assumed to be 0.1 mm/s. At the channel exit, condition is assumed to be ambient, which is at 1 atm. pressure. At the channel walls, no-slip boundary conditions are assumed. The molar concentration of one of the fluid species is set to 0 and the other as 20. By using above mentioned data and theory, we got analytical mixing length i.e 10 mm for Y shape without obstacles.

As the mixing takes place, the molar intensity on one side of the channel decreases from 20, while on the other side it increases from 0 onwards. Complete mixing is considered to be achieved when the molar intensity of 10±0.5 is reached for both the fluids.

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

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

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

The evolution of the concentration is computed from the advection diffusion equation.

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

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 shaped micro-mixer with different obstacles like triangular, rectangular and semicircular on channel wall.

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

Channel Inlet 1	Velocity at Inlet	0.1 mm/s
Channel Inlet 2	Velocity at Inlet	0.1 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 of obstacles in them are as shown below

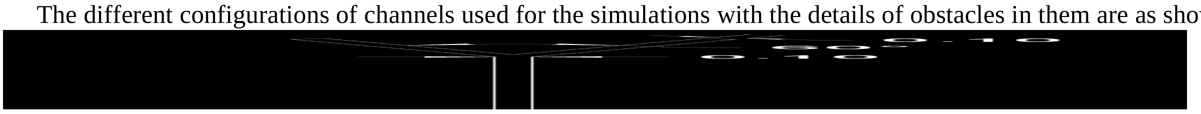

Figure 2 Y Channel without obstacles

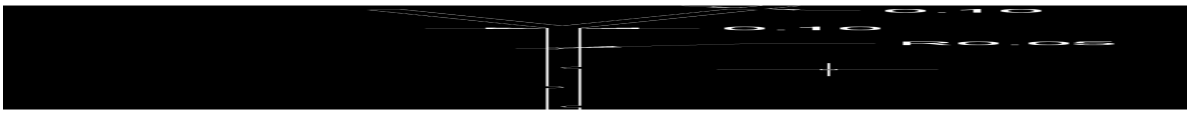

Figure 3 Y Channel with Circular Obstacles

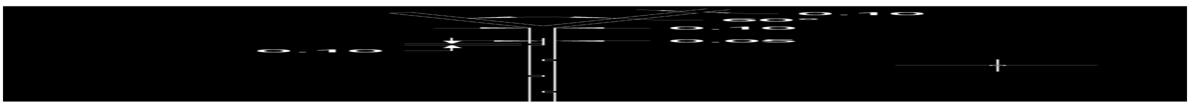

Figure 4 Y Channel with Rectangular Obstacles

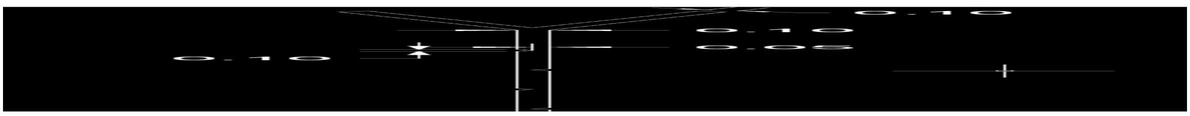

Figure 5 Y Channel with Triangular Obstacles

IV. RESULTS AND DISCUSSIONS

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

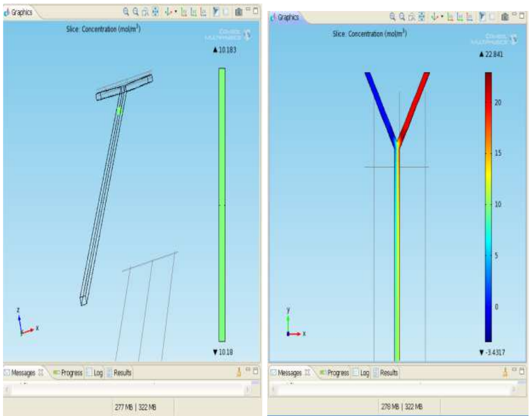

Figure 6 Simulation of Y Channel without obstacles

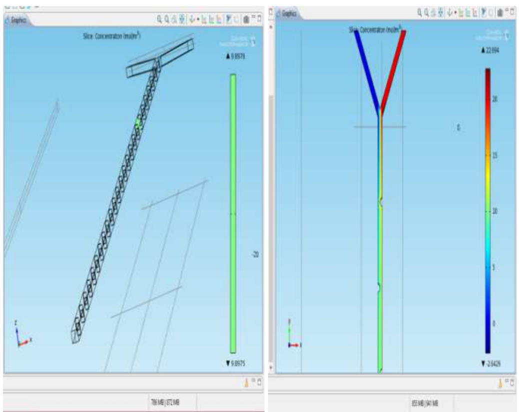

Figure 7 Simulation of Y Channel with Circular Obstacles

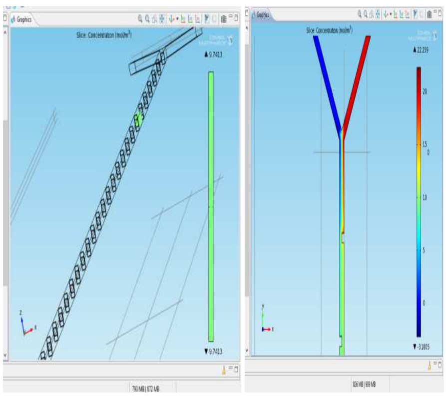

Figure 8. Y Channel with Rectangular Obstacles

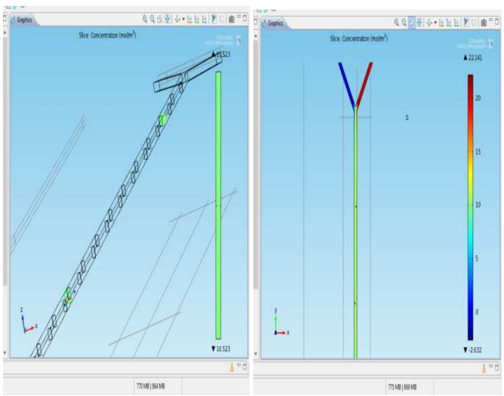

Figure 9. Y Channel withTriangular Obstacles

The simulation results for Y shapesd micro-mixer with different obstacles by changing spacing between them is summarised in Table I.

Table I Analysis of of Mixing length

Sr. No.	Y shape Channel Description	Mixing Length of 1mm Spacing Obstacles in mm	Mixing Length of 2mm Spacing Obstacles in mm	Mixing Length of 3mm Spacing Obstacles in mm
1	without obstacles	12	12	12
2	circular obstacles	9	9.5	10

3	rectangular obstacles	8	8.3	9
4	triangular obstacles	7	8	8.5

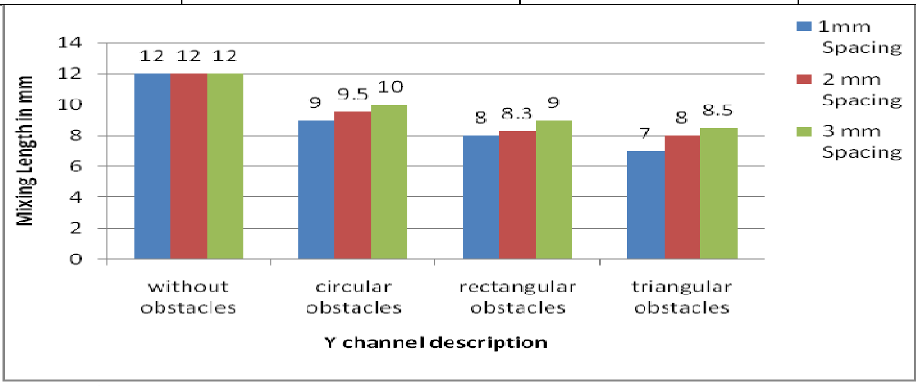

Figure 10 Comparision of Mixing lengths

The simulation results and the mixing length values inferred show that the mixing length is minimum for the channel with triangular obstacles when compared to other types of obstacles as shown in Fig.10. This may be due to the sharp corner of the triangular apex 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. Simulations on the fluid flow in full scale "Y" micro-mixer were performed in this study. To improve the mixing performance of "Y" micro-mixer, the use of obstacles were investigated. The effects of different obstacles located on the channel wall were studied for their effect on the mixing length in the channel by changing the spacing length. 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 obstacles can improve mixing performance by affecting the flow pattern.
3. The simulation results illustrate that mixing is enhanced as the number of obstacles increases i.e. with decrease in the spacing of the obstacles in the channel, the mixing length decreases.
4. Minimum mixing length was observed for the triangular obstacles in the micro-channel.

References

[1] Wang, Hengzi, Iovenitti, Pio, Harvey, Erol, Masood, Syed, Deam,"Mixing of liquids using obstacles in microchannels," BioMEMS and Smart Nanostructures, Laszlo B. Kish, Erol C. Harvey, William B. Spillman, Jr.,Editors, Proceedings of SPIE Vol. 4590 (2001) © 2001 SPIE · 0277-786X.
[2] Ali Asgar S Bhagat, Erik T K Peterson and Ian Papautsky "A passive planar icromixer with obstructions for mixing at low Reynolds numbers"Journal of Micromechanics and Microengineering J. Micromech. Microeng. 17 (2007) 1017–1024.
[3] Xueye Chen , Chong Liu Zheng Xu a,b, Jingmin Li, "An Analytical Macro-micro-model for a Micromixer" Journal of Information & Computational Science 7: 3 (2010) 785–797.
[4] A. Heeren, C.P. Luo, G. Roth, A. Ganser, R. Brock, K.-H. Wiesmueller, W. Henschel, D.P. Kern," Diffusion along microfluidic channels" Microelectronic Engineering 83 (2006) 1669–1672.
[5] Tijjani Adama, U. Hashima, Sutiknob, "Simulation of Passive Fluid Driven Micromixer for Fast Reaction Assays in Nano lab-on-chip Domain" International Conference on Advances Science and Contemporary Engineering 2012 (ICASCE 2012).
[6] S. Naher ,D. Orpen , D. Brabazon , C.R. Poulsen , M.M. Morshed ," Effect of micro-channel geometry on fluid flow and mixing" Simulation Modelling Practice and Theory 19 (2011) 1088–1095.
[7] Lorenzo Capretto, Wei Cheng, Martyn Hill, and Xunli Zhang," Micromixing Within Microfluidic Devices" Top Curr Chem (2011) 304: 27–68 DOI: 10.1007/128_2011_150 # Springer-Verlag Berlin Heidelberg 2011 Published online: 28 April 2011.

[8] Chia-Yen Lee , Chin-Lung Chang , Yao-Nan Wang and Lung-Ming Fu," Microfluidic Mixing: A Review " *Int. J. Mol. Sci.* 2011, *12*, 3263- 3287; doi:10.3390/ijms12053263.