International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume – 03, Issue – 04, April 2018, PP – 73-79

Comparative study of the Wing-shaped micromixer for the variation of depth function

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Abstract: In this paper, we have investigated the comparative study on the function of depth of passive Wing-shaped micromixer. The numerical simulation implemented by using the COMSOL Multiphysics package. We have studied the flow of a fluid which is Newtonian. Reynolds number has been over a wide range of 0.01 to 150 which show laminar behavior of the flow. We have assessed the micromixing performance by simulating for different ratios of depth to diameter. It is found that increase in the ratio of depth to diameter within the microchannel, enhance the mixing performance and results are better than straight microchannel.
Keywords: MEMS, BioMEMS, micromixer, microfluidics, COMSOL

I. INTRODUCTION

A significant group of the Microelectromechanical System (MEMS) is the BioMEMS, which have got numerous biological applications [1]. The biological MEMS often employ microfluidic systems, whose demonstrated potential has registered a major boost in the recent decades through their diverse applications in chemical and biological avenues. In microfluidic devices, the consistencies of applications necessitate the condition of laminar flow. The latter poses formidable challenges in the mixing of liquid samples, especially when the flow is constricted through a microchannel. In these conditions, the mixing is dominated by molecular diffusion instead of the turbulence at a micro-scale.

The study of mixing at microscale and development of micromixer has attracted great attention both in academics and industries [2]. Micromixer is used in several applications such as chemical reaction, Lab-on-chip (LOC), Micro-Total-Analysis-System (μTAS), medical diagnostic, DNA sequencing and drug delivery [3]. Micromixers forming an essential component of the above systems operate through different mixing mechanisms. The micromixers are classified into two types: active and passive. The active micromixers require external power to execute the task of micromixing. Commonly used sources of their energy are magnetic [4], electroosmotic [5], electrokinetic [6], magnetohydrodynamic [7], etc. The passive micromixers however employ no actuators and so they do not need external electrical power. Some examples passive micromixers designated by the principle of their operation are lamination [8, 9], chaotic [10], groove [11], etc.

II. LITERATURE SURVEY

Most of the passive micromixers utilize some innovative mechanism resulting from the design of their specialized structure, which forces the fluids flowing through it also undergo their own micromixing. Some explanatory examples of these are: the self-circulating flow micromixer [11] having circular mixing chamber that induces mixing even at low Reynolds number. Another example is the curved microchannel with the rectangular grooves on the side wall [12]. Then 3D chaotic serpentine microchannel was created [13] and it showed an improvement in the mixing. Non-periodic fractal patterns were introduced in slanted ridges at the bottom of the channel [14] and the mixing index based on the entropy was measured. It has been observed that bending structures in the microchannel enhance the mixing [15]. Different types of structures have been tried out and their performance of mixing has been compared [16]. The mixing performance of simple microtubes [17] improves when it is baffle to create orifice with half and quarter cross section. Trapezoidal blade structured micromixer in which flow of the fluid is repeatedly bent and twisted also creates vortices at low Reynolds number [18].

In the present work, we have investigated the mixing efficiency and pressure drop as a function of the depth of fluid flow within straight and wing-shaped chaotic advection micromixers through numerical simulation and compared their performance. In section III, we present the methodology used for conducting the numerical simulation. The geometry of the model is furnished in subsection A and the simulation details are provided in subsection B. The governing equations of the fluid flow and the meshing of the model are discussed in subsection C and the results of intensive simulations are discussed in section IV.

III. NUMERICAL SIMULATION

A. Geometry

To design the geometry of our micromixer, we have used COMSOL software tool [19]. The specifications of the straight channel are as follows: Both the inlets have a length of 1300 µm and their width is 300 µm each. The length of the main channel is 11000 µm and its width is also 300 µm. The geometry of the inward wing shaped channel are: the inlets, outlet, thickness and total length of the channel are of same size as that of the straight channel. The dimension of entrance of the main channel is 400 µm; the size of the inward wing on the side walls is 50 µm at the inner side of the channel. The wings are of the same thickness as that of the channel. We have simulated the characteristics of the mixer for different values of its relative depth viz. ¼, ½, ¾ and 1. Thus the actual values of depth of the channel considered for the simulation are 75 µm, 150 µm, 225 µm, 300 µm for straight as well as for the wing-shaped micromixer shown in Fig. 1. There are a total of 15 wings in the channel and thus it has 15 mixing units.

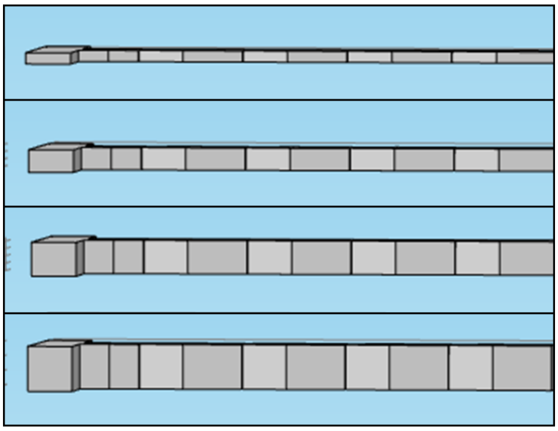

Figure 1.Wing-shaped micromixer with ¼, ½, ¾, and 1 thickness.

B. Simulation

For this simulation, the values used for various characteristics of water are: density as 1000 kg m^{-3}, dynamic viscosity as 10^{-3} kg/m s and diffusion coefficient as 1.2×10^{-9} m^2/s. The temperature kept constant at 25º C [298.15 K]. The concentration at inlet one was assumed to be 0 mol/m^3 and at the other inlet the concentration is 1 mol/m^3. A wide range of the Reynolds number viz. 0.01, 0.1, 1, 2, 3,…, 10, 20, 30, …, 150. The fluid flow has been assumed as steady, with no-slip at the wall. Pressure at the outlet was fixed at 0 Pa. The mixing characteristics for different depths of the straight and also the wing shaped micromixer have been compared to explore the region of best efficiency in the performance of mixing.

C. Governing Equations

The governing equations are the NavierStoke's (1), continuity (2) and convection diffusion (3) equation. These equations can be expressed respectively as follows:

$$\rho\left[\frac{\partial u}{\partial t}(u.\nabla)u\right] = -\nabla p + \mu\nabla^2 u \qquad (1)$$

$$\nabla u = 0 \qquad (2)$$

$$\frac{\partial c}{\partial t} = D\nabla^2 c - u.\nabla c \qquad (3)$$

Where ρ is the density, µ is fluid viscosity, p is fluid pressure and u is velocity, c is the species concentration, and D is the diffusion coefficient of the species.

We had performed fine tetrahedral meshing on the geometry for fluid dynamic. The above equations have been solved by finite element method shown in Fig. 2.

The mixing index was evaluated at the cross-sectional plane perpendicular to the axial direction shown in eq. (4). In order to do that, the variance was evaluated for the intensity of segregation. The variance of the species was determined on the cross-sectional plane normal to the flow direction. The degree of concentration of the mixture of fluids has been calculated by using the following expression:

$$M = 1 - \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{c_i-\bar{c}}{\bar{c}}\right)^2} \qquad (4)$$

Where M is the mixing index, N is the total number at the sampling points, c_i is the molar fraction values at the sample point i and $\bar{c}$ is the mean molar fraction value in the case of complete mixing.

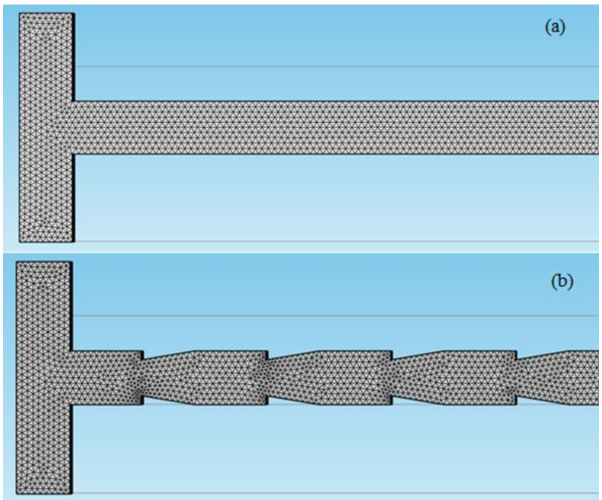

Figure 2. Mesh of a) Straight channel; b) Wing-shaped microchannel.

IV. RESULTS AND DISCUSSION

The values of concentration, pressure drop and mixing Index at the outlet plane as a function of Reynold's number for four different values of depth of the Straight and Wing-shaped microchannel have been evaluated and presented. Fig. 3 shows the concentration variation for the Straight microchannel. The concentration valve of the straight microchannel of depth 225µm shows the 0.5 mol/m^3 at Reynold's number 50.

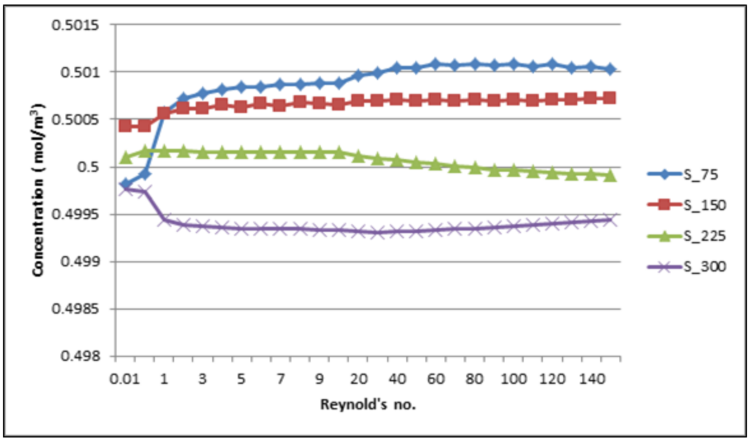

Figure 3. Concentration of the different depth of the Straigth microchannel.

Fig. 4 shows variation of concentration with Reynold's number of the Wing-shaped microchannel where channel of depth 225 µm have 0.5 mol/m^3 at Reynold's number 30. Thus for wing-shaped microchannel the mixing occurs for a smaller valve of Reynold's number than for the straight channel. But for the wing-shaped microchannel having a depth of 300 µm, complete mixing occurs only at Reynold's number value of 110.

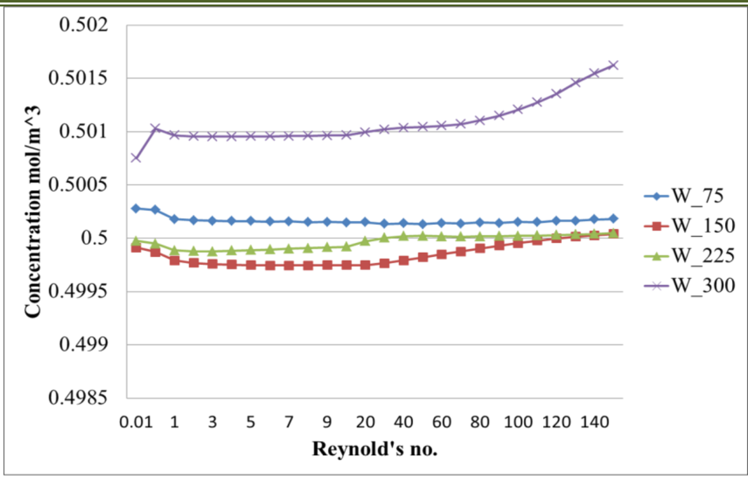

Figure 4. Concentration of the different depth of the Wing-shaped microchannel.

Fig. 5 shows the values of Pressure Drop as a function of Reynold's number occurring in a Straight microchannel. When Reynold's number is in the range 0.001-3.0, the value of the pressure drop is almost nil for different values of the depths studies. The effects of channel depth and the divergence between the four curves begin to show up when Reynold's number rise in the range between 4 and 10. We observe a non-zero value of pressure drop for a microchannel of depth 75 µm but channels of depth 150 µm, 225 µm, and 300 µm still register no visible drop in pressure. The value of pressure drop increases linearly with Reynold's number for all the microchannel. It has large positive gradient for the microchannel of depth 75 µm, moderate positive gradient for the microchannel of depth 150 µm and only a marginal linear rise for the microchannel of depth 225 µm and 300 µm.

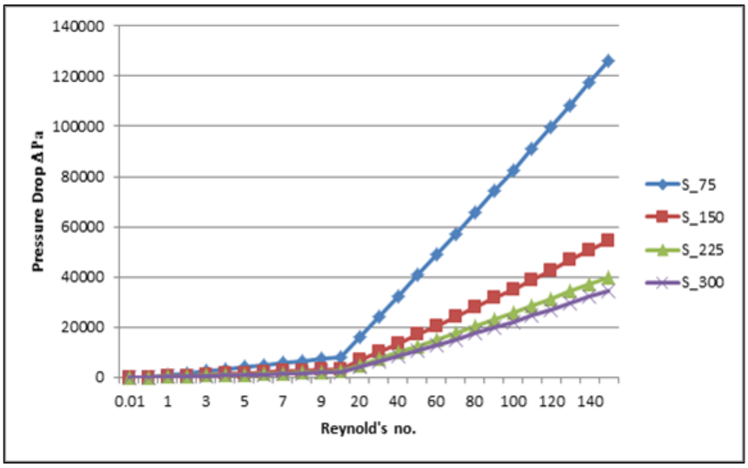

Figure 5. Variation of the Pressure Drop with the Reynold's number for different depth of the Straigth microchannel.

The pressure drop observed for the Wing-shaped micromixer is shown in Fig. 6. Its variation with Reynold's number for different values of channel depth displays a trend, which is essentially similar to that observed for the Straight microchannel.

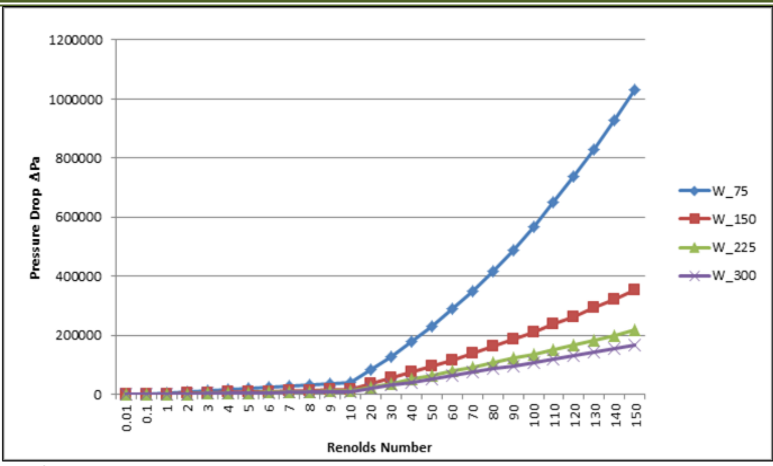

Figure 6. Variation of the Pressure Drop with the Reynold's number for different depth of the Wing-shaped microchannel.

Fig. 7 shows the values of Mixing Index as a function of Reynold's number for the Straight microchannel. It can be seen that the microchannel of depth of 75µm has mixing index of 0.55 whereas the channel of depth 300 µm has mixing index of 0.85. As the depth of the channel increases the mixing index increases.

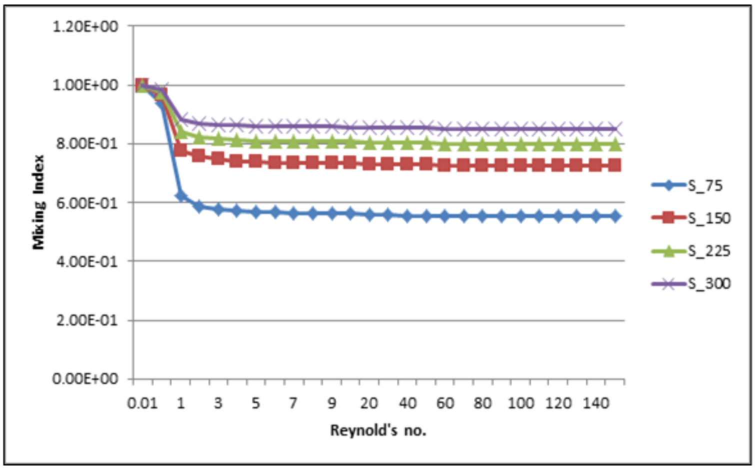

Figure 7. Mixing Index with respect to the Reynold's number for the Straigth microchannel.

Fig. 8 shows the variation in the values of mixing index at the outlet with Reynold's number for four different of the Wing-shaped micromixer. It is observed that the values of the mixing indices for winged channel are higher than those for the straight microchannel. As the Reynold's number increases from 0.01 to 5.0, the mixing index values diverge with channel depth. A winged-shaped channel of depth 75 µm delivers a mixing index of 0.88 and it is almost non-variant over a very wide range of Reynold's number. Channel with depth of 150 µm, 225 µm, and 300 µm gave mixing indices of 0.92, 0.97, and 0.99 respectively.

The fact that the mixing index observed for wing-shaped channels is higher than that for the straight channel may be attributed to the geometric design of the former, which supports a chaotic mixing of the fluids flowing through it. Due to the geometric design of the chaotic the mixing index increases.

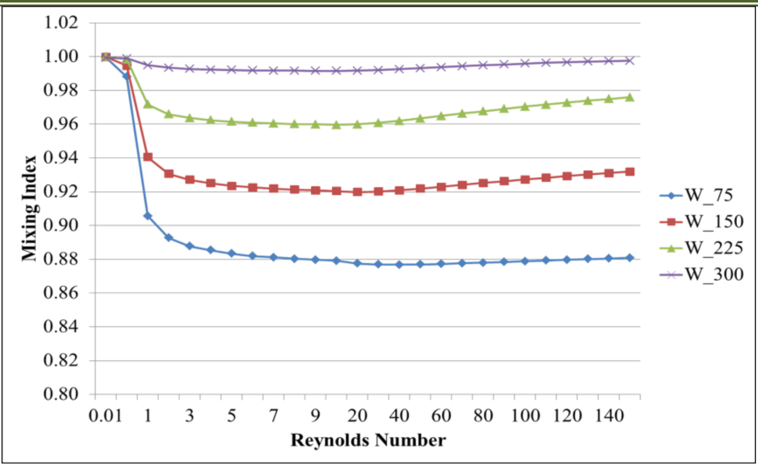

Figure 8. Mixing Index with respect to the Reynold's number for the Wing-shaped microchannel.

V. CONCLUSION

In this paper, we have investigated the mixing characteristics of the straight and wing-shaped micromixer for different values of their depth. Rigorous numerical simulation has been performed by using the simulation tool COMSOL. The variations in observed values of concentration, pressure drop and mixing index with Reynold's number have been compared for different values of channel depth. It is found that, as the depth of the microchannel increases the values of concentration and the mixing index increase and that of the pressure drop decreases. Mixing characteristics observed for the wing-shaped design of micromixer are better than those of the straight microchannel in every aspect.

Acknowledgements

We express our gratitude to Senior Professor, Dr. S. C. Mehrotra, Department of CS&IT, for his valuable discussion and moral support. We are thankful to Professor, Dr. B. N. Dole, Coordinator of National MEMS Design Center (NMDC) Lab at Department of Physics, Dr. B.A.M. University, for permitting us to utilize the NMDC lab. Author A.A. Khan thanks to University Grant Commission (UGC), India, for financial support by providing Maulana Azad National Fellowship (MANF)-Senior Research Fellowship (SRF).

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