ANALYSIS OF MIXING PERFORMANCE OF MICROMIXER WITH DIFFERENT OBSTACLES

Bappa Mondal, Assistant Professor, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127
Siva Amujuri, B.Tech. Student, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127
Sowmya G, B.Tech. Student, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127
Vignesh D.V.M.S, B.Tech. Student, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127
Sai Vamsi A, B.Tech. Student, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127
Vishnu Vardhan D, B.Tech. Student, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Vizianagaram, Andhra Pradesh - 532 127

Abstract
This work examines fluid mixing in microdevices with different geometries and how such design affects the efficiency of mixing the fluids, which often have different physical properties, like different densities and viscosities. The simulations show that for each fluid, the viscosity depends on composition and therefore influences the behavior of mixing. A telling result is that "positive fluidity of mixing" promotes an engulfment regime, which enhances the interfacial stretching and increases mixing. It not only increases the degree of mixing but reduces the critical Reynolds number that is, it requires less force to mix. The aspect ratio of the microchannel also influences mixing dynamics; the aspect ratio refers to the width-to-height ratio of the microchannel. This leads to minor aspect ratios providing fewer flow resistances but typically lower mixing strengths. The vortices generated by greater aspect ratios tend to be stronger, hence more robust in mixing, typically at relatively shorter channel lengths. This is due to the higher aspect ratios that enable secondary flows and rotational and chaotic motions associated with the process take place more effectively for fluid mixture homogenization.

Keywords:
Microchannel, Mixing Performance, Obstacles, Mixing Efficiency

I. Introduction
Micromixers play a critical role in modernizing various scientific domains, particularly in biomedical and biochemical sciences. They are essential in micro-total analysis systems and Bio Micro Electro-Mechanical Systems (BioMEMS), where efficient mixing in microchannels is crucial [1]. Micromixers are widely used in DNA analysis, cell storage, high-throughput screening, and dynamic cell separation. The literature classifies micromixers into active and passive categories. Active micromixers use external energy sources, such as ultrasonic vibrations or magnetic forces, to enhance fluid mixing, while passive micromixers rely on diffusion or chaotic advection without external energy [2].

Micromixers can be classified based on their mixing mechanisms, channel geometry, flow regime, application, and integration level. Active micromixers, like ultrasonic and electrokinetic mixers, use external energy to achieve efficient mixing [3]. Passive micromixers, such as static mixers and those with geometric modifications, enhance mixing through natural flow dynamics and structural design. Channel geometries include straight, serpentine, converging-diverging, and helical channels, each optimized for fluid flow and mixing efficiency. Additionally, micromixers can be tailored for specific applications, such as chemical reactors, biochemical assays, and environmental monitoring, and can be either standalone units or integrated into larger microfluidic systems [4].

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 11, No.4, November : 2024

Micromixers have numerous applications, especially in biological and biochemical sciences. In DNA analysis, micro mixing ensures uniform reagent distribution, enhances reaction efficiency, minimizes contamination, and optimizes reaction conditions. Lab-on-a-chip (LOC) devices benefit from micro mixing through thorough reagent mixing, rapid reaction times, reduced sample volumes, and improved reaction uniformity. In biological and biochemical sciences, micro mixing enhances reaction efficiency, ensures consistent results, minimizes reaction times, and improves cell culture and analysis outcomes [5].

Micro mixing is vital in BioMEMS due to the need for efficient mixing in small volumes, rapid reaction times, and homogeneous sample preparation. Enhanced mixing speeds up biochemical reactions, crucial for diagnostics and real-time monitoring. Micro mixing ensures uniform samples, which is essential for consistent and reliable assay results, particularly in high-throughput screening. Additionally, BioMEMS can integrate multiple steps, such as mixing, reaction, and separation, on a single chip, streamlining workflows and reducing reliance on external apparatus [6,7].

The main objective of this study is to quantifying the mixing efficiencies with different obstacles with different geometries. The main moto of this study is to analyze the flow rate effects and mixing index by changing the Reynold numbers and spacing between obstacles.

II. Methodology

The methodology involves geometric modeling of the microchannel and obstructions, followed by numerical simulation of fluid flow and mass transport. The primary objective is to analyze velocity fields, concentration distributions, and quantify mixing efficiency through the mixing index. The adopted methodology illustrates the mixing efficiency of various micromixer geometries at different Reynolds numbers (Re) as shown in the Figure 1.

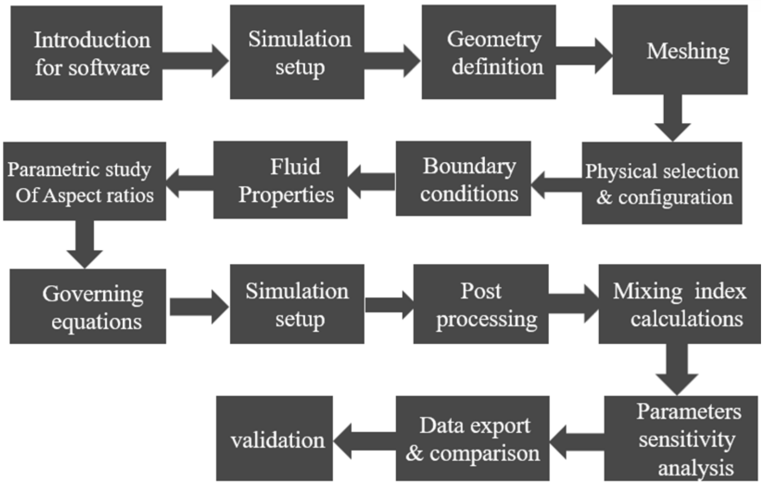

Figure 1: Simulation process flow chart

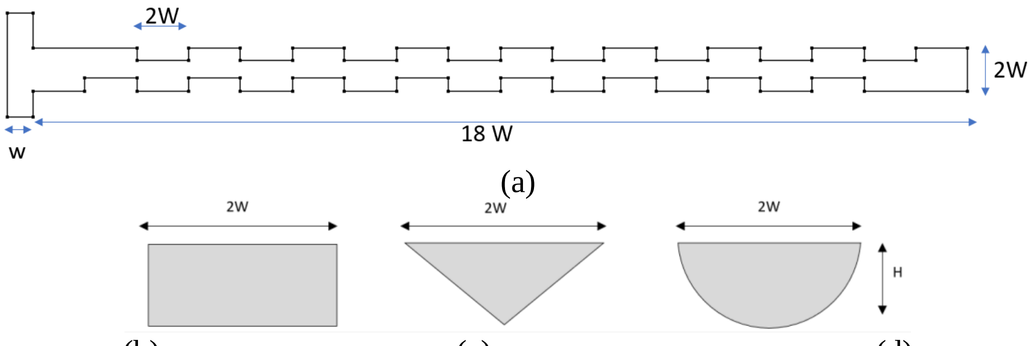

Figure 2: Schematic diagram of micromixer

Two-dimensional, steady, laminar, incompressible flow of Newtonian fluid through rectangular sections considered. The thermo-physical properties are constant. The Reynolds number varied from

0.1 to 50. This study conducted by varying the Reynold numbers with same section and changing the obstacles. Accordingly, the aim of the current investigation is to compare the mixing and pressure drop characteristics for flow through different obstacles like rectangular, semicircular, triangular, with varying Reynold numbers. In the considered geometry of the micromixer two inlets and one outlet are there. The width of the inlet and outlet section are 0.3 mm and 0.6 respectively, whereas the total length of the mixing channel is 54 mm. Three shapes of obstacles are considered such as rectangle, triangle, and semi-circular as shown the Figure 2 (b, c, d). The height and length of the obstacle are 0.25 mm and 0.6mm respectively.

III. Results and Discussion

The mixing efficiency of various micromixer geometries at different Reynolds numbers (Re) is illustrated in Figure 3 and Table 1.

Micromixer Geometry	Re						
	0.1	**1**	**5**	**10**	**20**	**30**	**50**
Without obstacle	17.06	36.45	55.18	66.71	75.475	81.958	85.77
With Triangular obstacle	38.12	47.65	66.71	76.24	81.005	85.77	90.535
With Rectangular obstacle	28.59	42.65	63.18	72.563	81.864	85.77	91.488
With Semicircular obstacle	19.06	38.12	57.18	71.24	81.005	86.2	92.441

Table 1: Mixing efficiency of various micromixer geometries at different Reynolds numbers

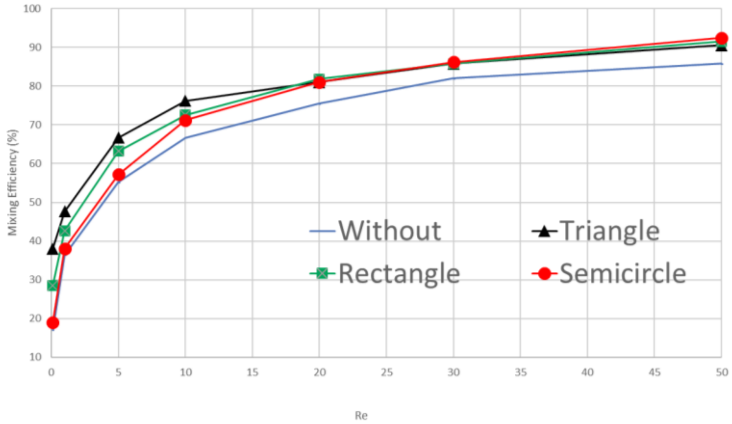

Fig 3: Mixing efficiency of various micromixer geometries at different Reynolds numbers

The mixing efficiency of different micromixer geometries at various Reynolds numbers (Re) is compared in Figure 4.6 and Table 4.1. At low Re (0.1), the triangle geometry achieves the highest efficiency (38.12%), followed by the rectangle (28.59%) and semicircle (19.06%), with the unmutilated configuration being the lowest (17.06%). As Re increases, the semicircle design shows significant improvement, reaching 92.441% efficiency at Re 50, outperforming the triangle (90.535%) and rectangle (91.488%). The unmutilated configuration improves with Re, achieving 85.77% at Re 50. Notably, for Re values between 35 and 50, all geometries converge to a mixing efficiency close to 90%.

The Figure 4 shows how mixing efficiency (%) changes across different geometries (1, 2, 3, and 4 means micromixer without obstacle, with triangular, rectangular and semi-circular obstacle respectively) for various parameter values (0.1, 1, 5, 10, 20, 30, and 50). Higher parameter values (10, 20, 30, and 50) result in consistently high mixing efficiency, staying above 70% across all geometries. In contrast, lower parameter values (0.1 and 1) show more variation, with efficiency dropping significantly, especially for 0.1. Geometry 2 stands out with a noticeable peak in efficiency for lower values. The parameter value 5 shows moderate efficiency, increasing slightly with geometries but not as high as larger parameters. Overall, higher parameters lead to better and more stable mixing efficiency.

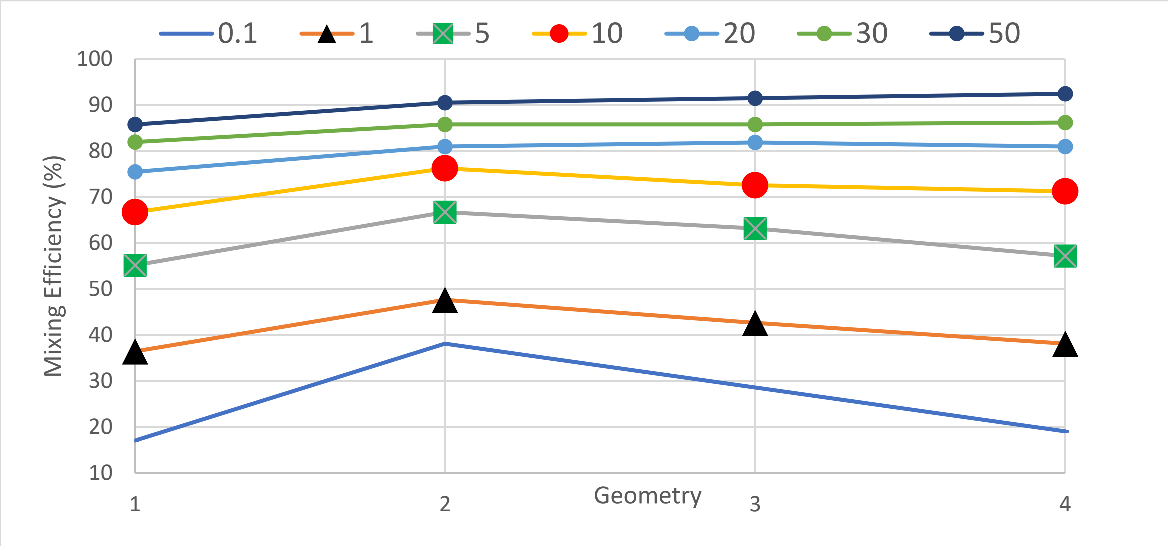

Figure 4: Comparison of mixing efficiency for different Geometries

IV. Conclusion

The outcomes of the study are summarized as follows:

- The mixing efficiency of a T-micromixer without obstacles at low pressure is significantly influenced by the Reynolds number. At low Reynolds numbers (0.1-1), mixing is primarily laminar, resulting in lower efficiencies of approximately 20-30%. As the Reynolds number increases, the flow transitions towards turbulent regimes, leading to enhanced mixing. At Re = 5, efficiencies typically range from 50% to 70%, and at Re = 10, they increase to 60-80%. For Reynolds numbers between 20 and 30, efficiencies are expected to be in the range of 80-90%. At higher Reynolds numbers (30-50), efficiencies can reach 85-95%.
- The addition of triangular obstacles to a T-micromixer significantly enhances mixing efficiency, particularly at lower Reynolds numbers. At Re = 0.1, efficiencies typically range from 30% to 50%, while at Re = 1, they improve to 40-60%. As the Reynolds number increases, the mixing efficiency continues to improve. For Re between 5 and 10, efficiencies typically range from 70% to 90%. At higher Reynolds numbers (10-20), efficiencies can reach 80-95%, and for Re between 30 and 50, efficiencies can be as high as 90-99%. It's important to note that the specific design of the obstacles and other factors can influence these values.
- Rectangular obstacles in a T-micromixer significantly improve mixing efficiency, especially at lower Reynolds numbers. At Re = 0.1, efficiencies range from 20% to 40%. As the Reynolds number increases, the mixing efficiency also increases. For Re between 1 and 5, efficiencies are typically between 40% and 70%. At higher Reynolds numbers (10-20), efficiencies can reach 75-90%, and for Re between 30 and 50, they can be as high as 90-98%.
- Semicircular obstacles in a T-micromixer can enhance mixing efficiency, especially at higher Reynolds numbers. At low Re (0.1), efficiencies are typically between 15% and 30%. As the Reynolds number increases, the mixing efficiency improves. For Re between 1 and 5, efficiencies range from 30% to 50%. At higher Reynolds numbers (10-20), efficiencies can reach 70-85%, and for Re between 30 and 50, they can be as high as 90-98%.

References

[1] Ta, B.Q., Le Thanh, H., Dong, T., Thoi, T.N. and Karlsen, F.,(2015). Geometric effects on mixing performance in a novel passive micromixer with trapezoidal-zigzag channels. Journal of Micromechanics and Microengineering, 25(9), p.094004.

[2] Khan, M., Shuja, S. Z., Yilbas, B. S., & Al-Qahtani, H. (2022). A case study on innovative design and assessment of a microchannel heat sink with various turbulators arrangements. Case Studies in Thermal Engineering, 31, 101816.
[3] Xuanyu, X., Zhu, C., Fu, T., & Ma, Y. (2022). Mass transfer intensification and mechanism analysis of gas–liquid two-phase flow in the microchannel embedding triangular obstacles. Chinese Journal of Chemical Engineering, 51, 100-108.
[4] Xueye, X., & Shen, J. (2017). Numerical and experimental investigation on splitting-and-recombination micromixer with E-shape mixing units. Microsystem Technologies, 23, 4671-4677.
[5] Alam, A. and Kim, K.Y., (2012). Analysis of mixing in a curved microchannel with rectangular grooves. Chemical Engineering Journal, 181, pp.708-716.
[6] Miranda, J.M., Oliveira, H., Teixeira, J.A., Vicente, A.A., Correia, J.H. and Minas, G., (2010). Numerical study of micro mixing combining alternate flow and obstacles. International Communications in Heat and Mass Transfer, 37(6), pp.581-586.
[7] Bappa Mondal, , Pati, S., & Patowari, P. K. (2020). Influence of confluence angle between inlets on the mixing performance of micro-mixer with obstacles. In Techno-Societal (2018).