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Numerical Investigation of Microfluidics Micromixer Integrated with Screw Element and Complex Micropillar Structure for Enhanced Mixing

Muhammad Waqas[1], Arvydas Palevicius[1]
[1] Faculty of Mechanical Engineering and Design
Kaunas University of Technology
Kaunas, Lithuania
Corresponding Author's muhammad.waqas@ktu.edu, arvydas.palevicius@ktu.lt

Summary:

This work presents the numerical investigation of three different microfluidics micromixer designs integrated with screw element and complex shape micropillar structure as a passive element. For this purpose, COMSOL Multiphysics with two physics such as laminar flow and transport diluted species to examine the fluid flow and mixing behavior inside a microchannel. The results revealed that the third micromixer design integrated with screw element and complex shape micropillar structures deliver a best mixing efficiency of 99.95% at Reynold numbers 1. In addition, the pressure drop from inlet to outlet is also examined that is 31.26502 Pa. The findings obtained from this study provide deep insights to examine the optimal micromixer design with larger mixing performance and lower pressure drop.

Keywords: micromixer, screw element, micropillars, mixing index, pressure drop

Introduction

Microfluidics technology has rapidly expanded into a vigorous interdisciplinary topic with considerable attention in a wide range of biomedical applications such as mixing, sorting and separation [1, 2]. The fluid flow through a microchannel is considered as a challenging task to control efficiently due to its tiny amount of sample. Mixing is one of the crucial processes for mixing various biofluids and chemicals [3]. Microfluidics micromixers are widely used for mixing purposes under laminar flow conditions. Annan Xia et al. [4] proposed a novel micromixer with "Tai Chi" structure with enhanced performance and low pressure drop. They examined mixing performance more than 50% and pressure drop less than 18000 Pa for all Reynolds number. A. Farahinia et al. [5] investigated a passive T shape micromixer with different geometrical configurations. They revealed the improved mixing efficiency up to 25%. Muhammad Waqas et al. [6] proposed a novel kind micromixer integrated with screw element. They optimized the optimal design with 98.47% mixing index. According to current literature, most of the researchers explored various kinds of micromixer with different geometrical configurations such as T-shape with zigzag pattern, Tai Chi shape etc. using active as well as passive approach but there is limited work has been explored by combining the different geometrical configurations such as integration of screw element and complex shape micropillar structures. The main objective is to design and perform numerical simulations of microfluidics micromixer integrated with and without screw element and complex shape micropillar structure for enhanced mixing at various Reynolds numbers. In addition, comparison study is also carried out to evaluate the optimal micromixer design with enhanced mixing performance. The findings from this research work have meaningful practical and theoretical worth in biomedical field.

Microfluidics Micromixer Design

Three different microfluidics micromixer desigs such as plane micromixer, integrated with screw element generates the rotational flow for better mixing and integrated with complex shape micropillar structures creates vertexes which increase the mixing. Figure 1 illustrates the optimal design of micromixer with geometrical dimensions.

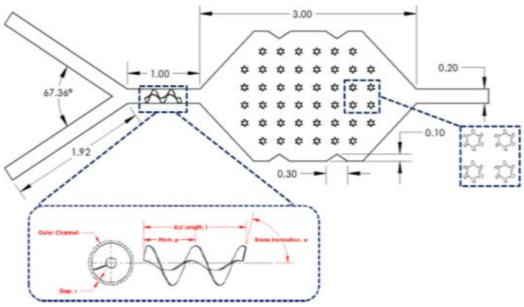

Fig. 1. Microfluidics micromixer design

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Computational domain and Meshing

Figure 2 shows the computational domain with two inlets and one outlet where water and ethanol are injected and mixed solution is collected respectively. In addition, tetrahedral mesh elements are used for meshing due to the channel's complex geometry.

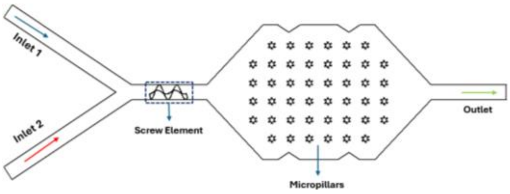

Fig. 2. Computational domain

Physics and Performance Parameters

Two physics such as laminar flow and transport of diluted species are used to model fluid flow and mixing of reactive species. Mixing index and pressure drop serve as performance parameters, with the mixing index calculated using the following equation.

$$MI = 1 - \sqrt{\frac{\sigma^2}{\sigma^2_{\max}}} \quad (1)$$

Results

Figure 3 shows the variation of mixing index with Reynolds numbers (1, 10, 50, 100) for three designs. Design 3 achieves the highest efficiency (99.95%) at Re = 1, while the plane micromixer shows the lowest (68.57%) at Re = 100.

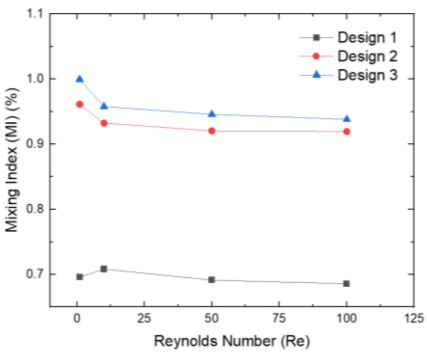

Fig. 3. Variation of mixing index with different Re

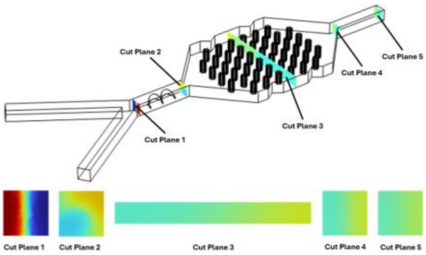

Fig. 4. Mixing concentration at five different cut planes

The screw and micropillar structures induce rotational flow and micro-vortices, enhancing diffusion at low Reynolds numbers. Figure 4 illustrates mixing concentration at five cut planes along the channel, highlighting mixing before and after passive elements, with green indicating optimal mixing (0.5 concentration). Figure 5 shows the pressure drop along the channel, caused by passive elements like screws and micropillars. The highest pressure drop, 31.27 Pa, occurs in design 2 at Re = 100.

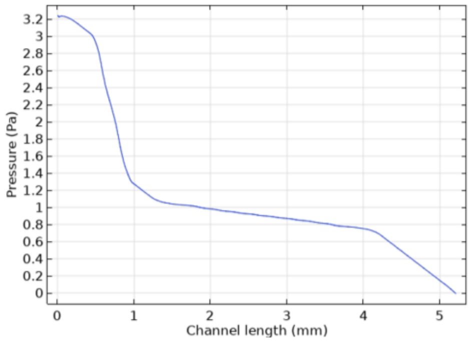

Fig. 5. Pressure drops along the channel length

Conclusion

Numerical simulations of three different micromixer designs are carried out using to investigate the mixing performance at different Reynolds numbers. Third, micromixer design delivers the best mixing performance compared to other designs. The findings can be beneficial for researchers to design optimal micromixers with enhanced mixing efficiency and lower pressure drop.

References

[1] Z. Li, B. Zhang, D. Dang, X. Yang, W. Yang, and W. Liang, "A review of microfluidic-based mixing methods," Sensors Actuators A Phys., vol. 344, no. June, p. 113757, 2022, doi: 10.1016/j.sna.2022.113757.

[2] M. Waqas and V. Naginevicius, "Numerical Investigation of Micromixer Using Hybrid Actuation Approach," Int. Conf. Perspect. Technol. Methods MEMS Des., no. May, pp. 108–112, 2024, doi: 10.1109/MEMSTECH63437.2024.10620043.

[3] M. Juraeva and D. Kang, "Mixing Performance of the Modified Tesla Micromixer with Tip Clearance," 2022.

[4] A. Xia et al., "Numerical and Experimental Investigation on a 'Tai Chi'-Shaped Planar Passive Micromixer," Micromachines, vol. 14, no. 7, 2023, doi: 10.3390/mi14071414.

[5] A. Farahinia and W. J. Zhang, "Numerical investigation into the mixing performance of micro T-mixers with different patterns of obstacles," J. Brazilian Soc. Mech. Sci. Eng., vol. 41, no. 11, 2019, doi: 10.1007/s40430-019-2015-1.

[6] M. Waqas, A. Palevicius, V. Jurenas, K. Pilkauskas, and G. Janusas, "Design and Investigation of a Passive-Type Microfluidics Micromixer Integrated with an Archimedes Screw for Enhanced Mixing Performance," Micromachines, vol. 16, no. 1, 2025, doi: 10.3390/mi16010082.