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Design and Simulation of Passive T-Micromixer for Improving Mixing Performance

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Abstract In micromixer, it can be classified into two group which is passive micromixer and active micromixer. This paper would be focusing on passive micromixer which is a T-shaped micromixer that is simpler in designing when comparing to active micromixer as there is external force needed. In passive micromixer, the mixing performance depends on the geometry design of the micromixer as certain implementation can improve the mixing performance of the passive micromixer. In this analysis, two design of T-micromixers were evaluated based on the T model micromixer performance. The micromixers are T-shaped micromixer with Cantor fractal structure and T-shaped micromixer with semicircular ridges. These micromixers have 5000 μm channel length, 300 μm channel width, inlet width and length are 300 μm and 1000 μm, respectively. The flow rate of the inlet is set at 1.5 (10^{-14}) m^3/s and the two solutions are set at the concentration of 5 mol/m^3 and 5 mol/m^3 to analyze the mixing performance of each of the T-shaped micromixer. T-shaped micromixer with Cantor fractal structure is analyzed to be the better implementation on the T-shaped micromixer as it has the lowest value of the standard deviation of concentration at the end of the mixing channel when compared to the other T-micromixer which is almost to the value of 0.

Keywords: Passive Micromixer, Cantor Fractal, T-Micromixer

1. Introduction

MEMS (Micro-electromechanical systems) refer to the use of mechanical and electrical components in order to create a small-scale integrated circuit or device. In the field of MEMS all the devices that is fabricated can be used to perform in microscale such as to control and actuate in the microscale but the effects would result in the macroscale. Microfluidic devices are any device that is related with the use of fluid in the microscale level. Few examples of microfluidic devices are micropump, microvalve and micromixer. Interest in microfluidic devices has been increasing throughout the years [1] such as in the bio-medical field. The application of microfluidic devices in the bio-medical field has been able to replace the traditional routine analysis and produce faster analysis. One of the examples for the application of microfluidic devices in bio-medical field would be the Lab-

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On-A-Chip (LOC) technology. This technology has made the analysis of a drop of blood possible due to the reduced volume and dimensions in the channels [2]. For LOC, most of the microfluidic device that is integrated with it is passive micromixer. The use of LOC devices are low cost and less power consumption as the use of sample is in a small amount [3].

In microfluidic systems, efficient mixing is really important as micromixer are used widespread in the industries. Micromixers are grouped into two type which is passive micromixer and active micromixer. For active micromixer to function, an external force is needed while for the passive micromixer no external force is needed [4]. In terms of simplicity of the design, passive micromixer is more simple than active micromixer. Therefore, it is more to be use than active micromixer. The mixing of passive micromixers is done by chaotic advection and molecular diffusion [5]. Many research has been done in order to improve the mixing performance of micromixer. Some of the studies that has been done is the implementation of fractal structure and obstacle-based micromixer

A fractal can be defined by the repetition of certain pattern under a few stages of magnification [6]. A few researches that are focusing on implementing fractal structures on passive micromixer has been reported on these past years. Chen et al. [7] implement the Koch fractal structure on a passive T-type micromixer with a primary fractal and secondary fractal. Seven Wall fractal structure micromixers were studied by Zhang et al. [8]. Chen et al. [9] implement the Minkowski fractal principle. All of the studies have been concluded as to have a better mixing performance when comparing to the basic micromixer. By adding obstacle to the microchannel, the mixing can be done by chaotic advection. Numerical analysis done by Shi et al. [10], which uses the array Koch fractal as the obstacle, shows that the mixing efficiency can improve to more than 95% when $R_e = 100$.

2. Model Design

For the modelling of the micromixer, the inlet will have the length of 1000 µm and width is equal to 300 µm. The length and width of the mixing channel will be design with the value 5000 µm and 300 µm. The length and width of the inlet and mixing channel will be applied in the three designs of the T micromixer. Figure 1 shows the geometry design of basic T micromixer.

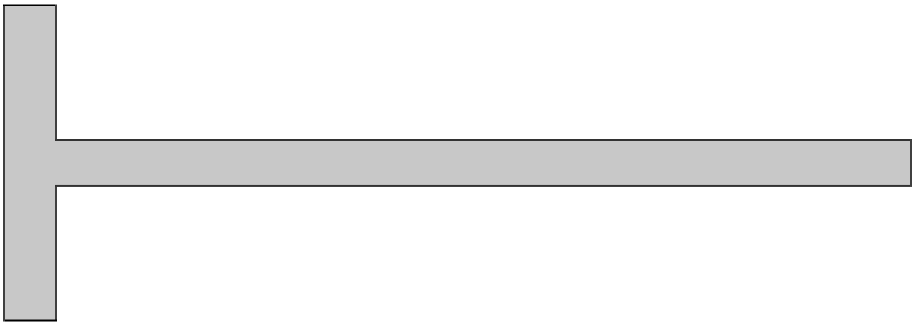


Figure 1: Geometry design of T micromixer

2.1 Micromixer with Cantor Fractal Structure

A simple fractal geometry is design and called Imitate Cantor Structure (ICS). A straight line specified with the length of 1000 µm and label as L. Next the height is set at 200 µm and with the L1 is equal to 125 µm which is the division of L with the value of 8. Next step, the value of L2 is equal to 31.25 µm which is the division of L1 with 8. The height for when the length is L2 is set at 100 µm. The ICS design is shown in Figure 2. The Implementation of Cantor fractal structure will use the four quadratics fractal with up-down arrangement. Figure 3 shows the modelling of the T micromixer with Cantor fractal structure.

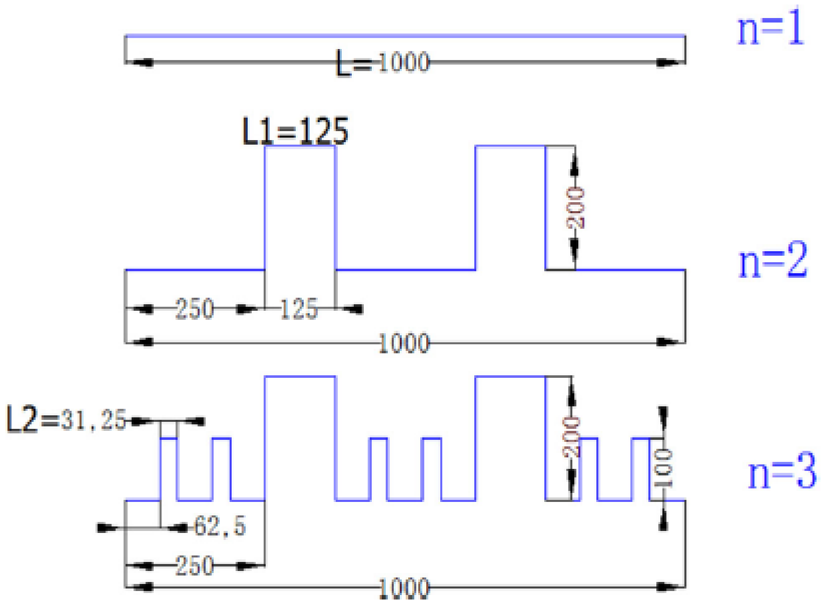


Figure 2: ICS design model

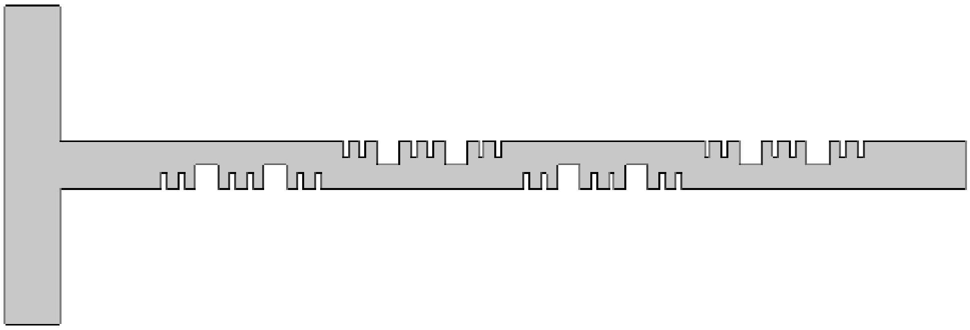


Figure 3: Geometry design of T micromixer with Cantor fractal structure

2.2 T-micromixer with semicircular ridges

The convex semicircular will have a diameter 160 µm and thickness of 50 µm. In every 500 µm in the mixing channel, a convex semicircular having a radius of 80 µm. The first obstacle will be added when the mixing channel length is at 1000 µm. Figure 4 shows the convex semicircular obstacles that will be added on the micromixer. Figure 5 shows the modelling of T micromixer with semicircular ridges.

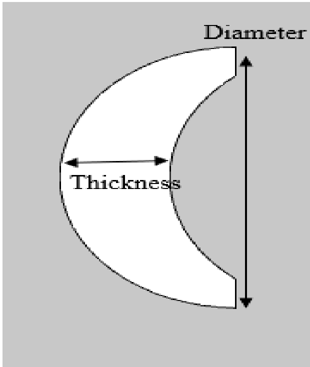


Figure 4: Geometric design for semicircular obstacle

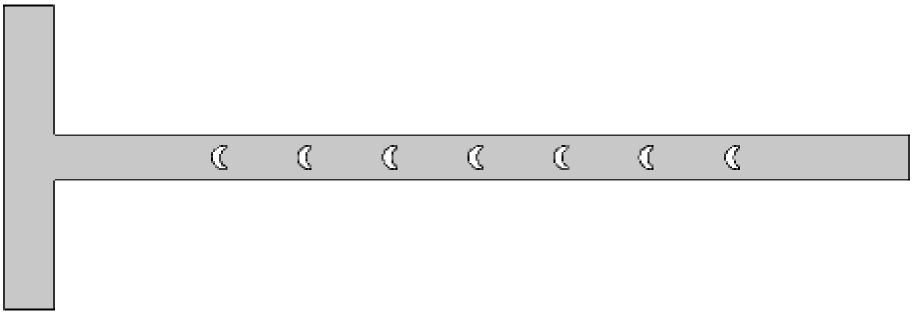


Figure 5: Geometry of T micromixer with semicircular obstacle

2.3 Equations

In analyzing the mixing performance of micromixer, finite element theory is used. The Navier–Stokes's equations and the continue equations are usually used to describe the dynamic properties of velocity and pressure for incompressible fluidic flows, whose form can be expressed as follows:

$$\rho[\frac{\delta u}{\delta t} + (u\,.\nabla u] = f - \nabla p + \nabla^2 u \qquad Eq.1$$

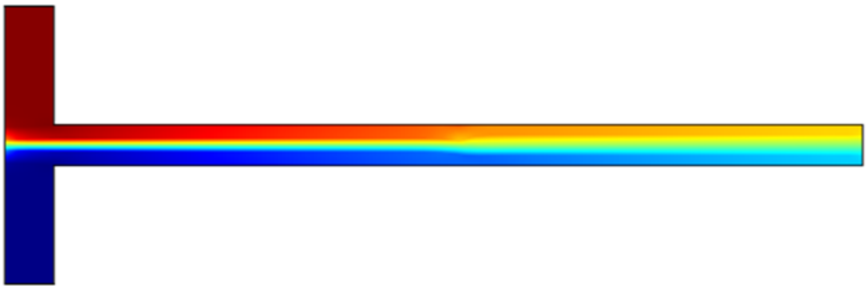
$$\nabla.u = 0 \qquad Eq.2$$

where u is the velocity vector, f is the body force, ρ q is the density of the fluid, p is the pressure, t is the time.

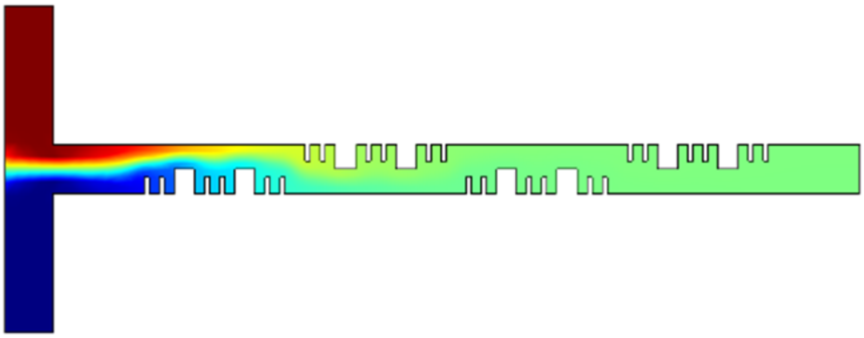
3. Results and Discussion

3.1 Mixing of T-micromixer

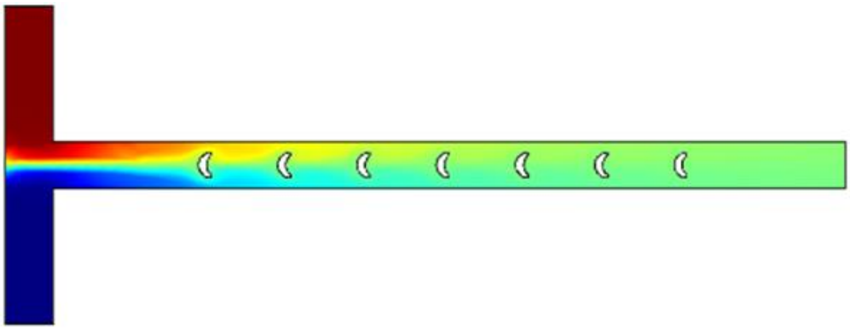
Figure 6 shows the concentration mixing for the T micromixer which the mixing performance of each T micromixer are analysed. For the mixing of T micromixer, it depends on diffusion therefore a long mixing channel is needed for the solution to fully mix. For the mixing in T micromixer with Cantor fractal structure, it is observed that is has a better mixing in comparison with the basic T micromixer. The fluid flow of the micromixer can be seen to be folding when the liquids are passing through the mixing channel. From the first obstacle of the Cantor fractal structure, the folding of the liquid can be seen clearly. In the mixing of T micromixer with semicircular obstacle, the fluid flow in the micromixer can be seen to be folding but it is not as intense as the folding in the T micromixer with Cantor fractal structure and the folding of the liquid is observed to be slower as it only occurs when passing through the semicircular obstacle.



(a)



(b)



(c)

Figure 6: Concentration of (a) T micromixer, (b) T micromixer with Cantor fractal structure, (c) T micromixer with semicircular ridges

3.1 Analysis of T-micromixer

Figure 7 shows the plotted graph of the standard deviation value for concentration mixing in T micromixer. By observing in Figure 7, it can be seen that the standard deviation value is decreasing as the mixing channel length is increasing but the value of the standard deviation is decreasing at a slow rate and at the end the end of the mixing channel, the value for the standard deviation of the concentration is not close to 0 which means that the solution is not completely mixed. At the end of the mixing channel the standard deviation is observed to be at 0.687910907. In order for the solution in T micromixer to completely mixed, a longer mixing channel is needed.

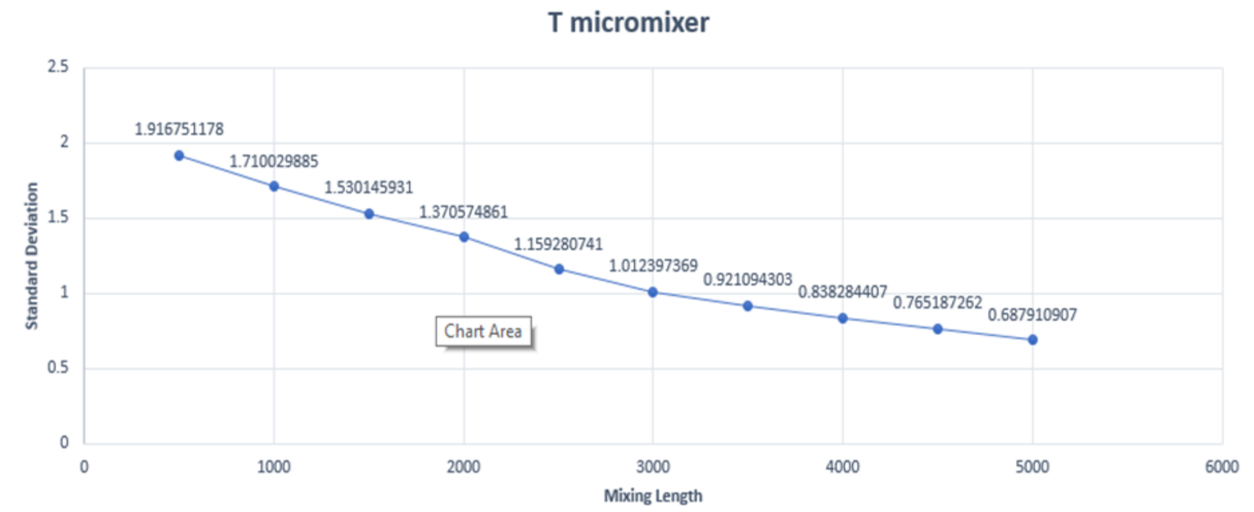


Figure 7: Concentration's standard deviation of T micromixer vs Mixing channel length

3.2 Analysis of T-micromixer with Cantor fractal structure

Figure 8 shows the plotted graph of the standard deviation value for concentration mixing in T micromixer with Cantor Fractal structures. Based on Figure 8, the standard deviation value shows a significant drop when the solution reaches the mixing channel length of 1000 µm. The standard deviation value changes from 1.497099751 to 0.676615964 which that rapid mixing occur in the mixing channel. With the implementation of Cantor Fractal structure in T micromixer, the standard deviation value of concentration is seen be almost at 0 at the mixing channel length of 2500 µm. As the mixing channel length increase, the standard deviation value can be seen decreasing even more and by the end of the mixing channel, the standard deviation value is observed to be at 0.00165067. This can interpret as the mixing to be nearly mixed as the standard deviation becoming even closer to 0. For the mixing in T micromixer with Cantor fractal structure to be complete, the mixing channel length will need to be increase and adding another Cantor fractal structure.

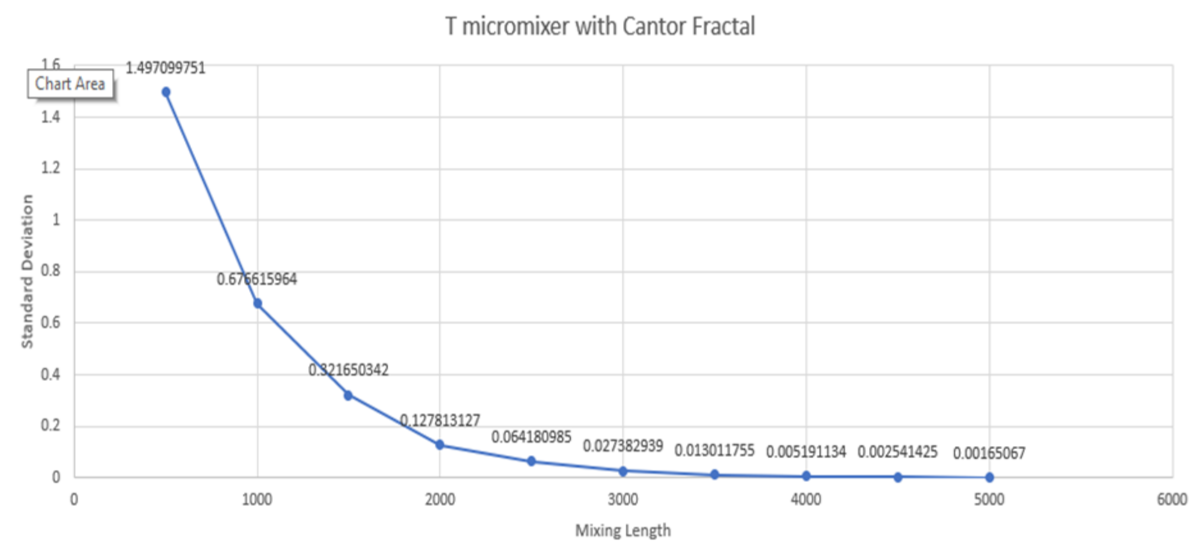


Figure 8: Concentration's standard deviation of T micromixer with Cantor Fractal structures vs Mixing channel length

3.3 Analysis of T-micromixer with semicircular ridges

Figure 9 shows the plotted graph of the standard deviation value for concentration mixing in T micromixer with semicircular ridges. From Figure 9, the standard deviation value in T micromixer with semicircular ridges can be observed to have a significant drop in its value at the mixing channel length of 1000 µm which the value changes from 1.219133976 to 0.554988923. This observation shows that when the solution reaches at the mixing channel of 1000 µm the mixing of the solution has become rapid and by the end of mixing channel length the value of the standard deviation has become 0.033338213 which almost to the value of 0. This shows that the mixing is better than the mixing in T micromixer and the mixing in T micromixer with semicircular ridges would result in the mixing of two solution to be almost completely mixed. This due to the implementation of adding obstacle in the mixing channel which cause the mixing to be done by diffusion and chaotic advection that is cause by the obstacle that is implemented. In order for the mixing to be complete, mixing channel length would need to be increase or the number semicircular ridges would need to be added in the mixing channel.

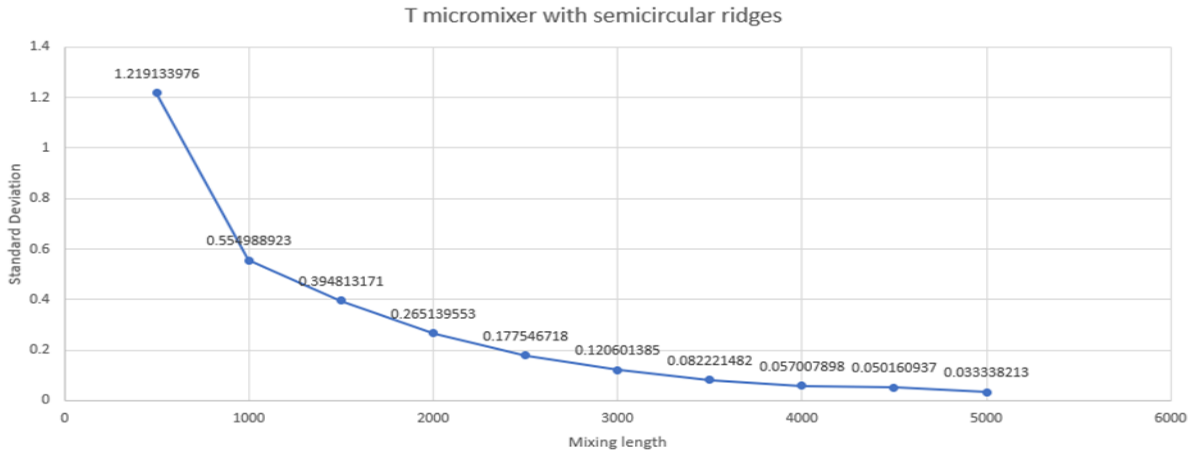


Figure 9: Concentration's standard deviation of T micromixer with semicircular ridges vs Mixing channel length

3.4 Comparison of the T-micromixer

Figure 10 shows the comparison in the concentration's standard deviation of each T micromixer. From Figure 10, the mixing performance in T micromixer is observed to be at the lowest when compare to T micromixer with Cantor Fractal Structure and T micromixer with semicircular ridges. In comparing the mixing performance of T micromixer with Cantor Fractal structure and T micromixer with semicircular ridges, both of the T micromixer has a good mixing performance as the standard deviation value for both micromixers started to decrease significantly when it reaches the mixing channel of 1000 µm. The micromixer with the best mixing performance is T micromixer with Cantor Fractal structure. This is because the mixing can be seen to nearly mixed at mixing channel length of 2500 µm and by the end of the mixing channel length, the standard deviation of T micromixer with Cantor Fractal structures is observed to be at the lowest value when compared to the standard deviation of the other T micromixer.

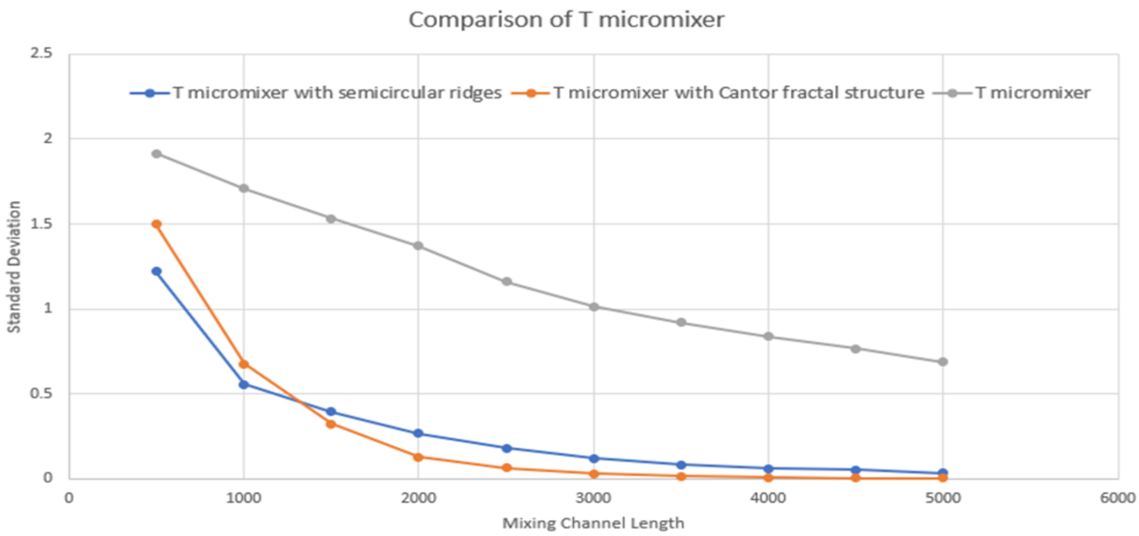


Figure 10: Comparison of concentration's standard deviation value for each T micromixer

Table 1: Comparison of standard deviation of each micromixer

Type of T micromixer	Standard Deviation
Basic	0.687910907
Cantor fractal structure	0.00165067
Semicircular ridges	0.033338213

4. Conclusion

It can be concluded that with the optimization of design in T micromixer, the mixing performance of the micromixer can be improved as the standard deviation value is close 0 which shows that the data points are almost near the value of the mean. In comparison with the T micromixer with cantor fractal structure and T micromixer with semicircular ridges, it can be conclude that T micromixer with Cantor fractal structure has a better mixing performance as the fluid flow shows that the liquid is folding in mixing channel at the first Cantor fractal obstacle and the standard deviation value of concentration is the most nearest to the value of 0 at the end of the mixing channel which implicates that the value of concentration in the end of the channel is almost equal to the value of the mean which is 7.5. For recommendations in improving the mixing performance, research on the mixing performance of T micromixer with Cantor fractal structure and semicircular ridges can be done to study the effect of implementing both of the optimized designs on the same micromixer as both result shows that the mixing performance improves when analyze.

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References

[1] Wu, Z., & Chen, X. (2019). A novel design for 3D passive micromixer based on Cantor fractal structure. Microsystem Technologies, 25(1), 225-236

[2] Lafleur, J. P., Jönsson, A., Senkbeil, S., & Kutter, J. P. (2016). Recent advances in lab-on-a-chip for biosensing applications. Biosensors and Bioelectronics, 76, 213-233

[3] Khalid, K. N., Jamil, M. A., & Hamid, I. A. (2013). A Comparative Analysis of Mixing Performances of Passive Micromixer for Laminar Blood Mixing. Journal of Engineering Technology, 3, 23-27

[4] Cai, G., Xue, L., Zhang, H., & Lin, J. (2017). A review on micromixers. Micromachines, 8(9), 274

[5] Raza, W., Hossain, S., & Kim, K. Y. (2020). A Review of Passive Micromixers with a Comparative Analysis. Micromachines, 11(5), 455

[6] Chen, X., Li, T., Shen, J., & Hu, Z. (2016). Fractal design of microfluidics and nanofluidics—A review. Chemometrics and Intelligent Laboratory Systems, 155, 19-25

[7] Chen, X., & Zhang, S. (2018). 3D micromixers based on Koch fractal principle. Microsystem Technologies, 24(6), 2627-2636

[8] Zhang, S., Chen, X., & Yang, D. (2019). Numerical study on micromixers with Wall-Fractal structure. Microsystem Technologies, 25(2), 521-530

[9] Chen, Y., & Chen, X. (2019). Numerical Investigations of a Passive Micromixer Based on Minkowski Fractal Principle. International Journal of Chemical Reactor Engineering, 18(2)

[10] Shi, X., Wang, L., Huang, S., & Li, F. (2019). A novel passive micromixer with array of Koch fractal obstacles in microchannel. Journal of Dispersion Science and Technology, 1-12