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Design and Simulation of 3D Micromixer with Planar Microchannel

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Abstract: Active and passive micromixers are the two types of micromixers. Passive micromixers will be the focus of this study due to their easy manufacturing procedures and quick implementation in a complex microfluidic environment. The passive micromixer is the safest kind of fluid mixing because of the laminar flow (Reynold number 1). For performance mixing, passive micromixers frequently rely on channel geometry. Based on the basic planar model micromixer baseline performance, three different micromixers were tested in this study. The micromixers are basic planar T-shaped micromixer in the first optimized design. Concept of planar B-spline and Tesla with a grooved meandering surface with obstacle inside the channel is the second and third optimized design. These micromixers have a 40 mm channel length, 10000 μm inlet length, and 600 μm m and 100 μm width and depth, respectively. To analyze the mixing performance of each planar micromixer design, the inlet flow rate is set at 0.07m/s and the two solutions are set at concentrations of 30 mol/m3 and 20 mol/m3. Planar B-spline micromixer design with obstacle inside the channel is analyzed to be as the better implementation on the basic planar micromixer as it has complete the mixing value of the standard deviation of concentration at the end of the mixing channel when compared to the basic planar micromixer, the standard deviation of planar B-spline micromixer is observed to be at the lowest value and mixing faster when compared to the standard deviation of the other planar micromixer design.

Keywords: Micromixer, Planar Microchannel, Mixing Channel

1. Introduction

Micromixers are key technologies in fields such as the chemical industry, pharmaceutical industry, analytical chemistry, biochemical analysis, and high-throughput synthesis because they use miniaturization of the fluids involved in the mixing to reduce quantities involved in chemical and biochemical processes [1]. Two types of micro-mixers are passive and active mixers. An active mixer uses an external energy source, which can be electric or magnetic, to perform the mixing of the fluids.

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Meanwhile, for the passive mixers there is no power source employed and basically, pressure guides the flow of fluids [2]. Microfluidics technology is a technology for controlling and manipulating dimensional (2D or 3D) fluids with sizes ranging from tens to a hundred micrometers in channels. Micro-mixer is one of the microfluidic devices used to mix fluids based on mechanical micro-parts [3].

Micro-mixers are a crucial component of microfluidic instruments used for the biochemical study of complex enzyme reactions and one of the most significant microfluidic systems, which manifests an important package in chemistry and biochemistry [4]. Micromixer can be categorized as active and passive micromixer [5]. Active micro-mixers required external sources for the mixing process such as thermal energy [6]. For passive micromixer, the fluid go with the flow charge inside the micro-mixer devices is meager. The fluids within the microchannels are laminar drift with the Reynolds number <1, displaying fluid flows without interruption among the layers in parallel layers. Mixing of the fluids relies upon on diffusion with the deficient mixing overall performance [7]. Current work on the micromixers has now been done on the simulation cycle. In any case, for the manufacturing cycle, the molds got after the assembling interaction has not enhanced and affect the mixing execution of the liquid [8].

To improve mixing efficiency in a micromixer, the effect of mass transfer in a mixture of microchannels, which provides the concept of molecular diffusion information, will be investigated [7]. The passive micromixer relies on molecular diffusion and chaotic advection, as previously mentioned. [10] A planar micromixer is a standard passive micromixer. The previous studies by Hamid et al. compare eight planar micromixers with two different chambers and four obstacle geometries are carried out by using three dimensional (3D) Navier–Stokes equations at the range of 0.1–40 of the Reynolds (Re) [6]. Stroock et al. [11] did the previous study on the effect of surface geometry on the mixing efficiency of micromixer. The use of patterned or grooved surfaces in flow geometry has shown promise in the development of three-dimensional flows that allow for stream mixing and demonstrate, using analytical and experimental methods, that simple patterns of grooved regions in a microchannel can produce three-dimensional flow structure in laminar flow.

2. Micromixer Design

For the modeling of the micromixer, the width, and length of the mixing channel are 600 μm, and 40 mm and fixed for the optimized microchannel. The T inlet channel width and length are also set for the optimized microchannel of 10000 μm and 600 μm, the mixer depth being 1000 μm. Figure 1 shows the 3D geometry design of a basic planar micromixer

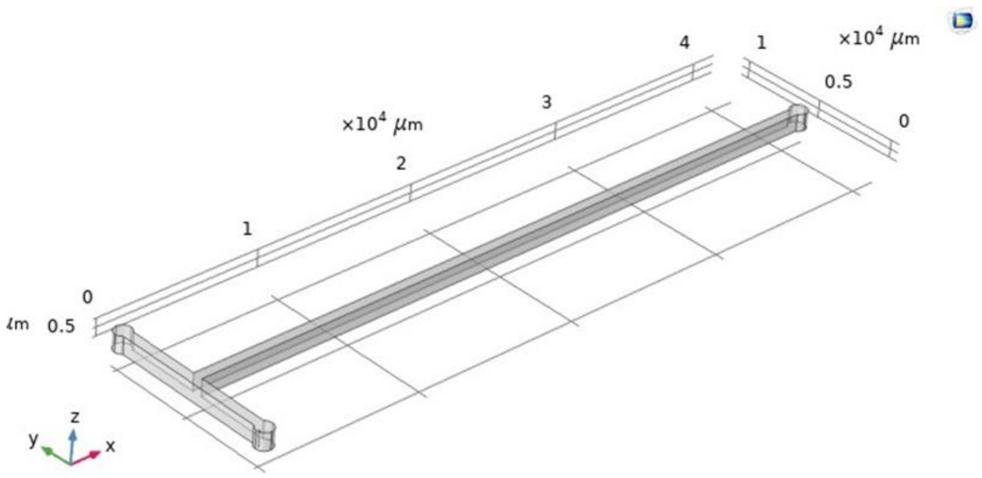

Figure 1: 3D geometry design of basic planar micromixer

2.1 Planar B-spline Micromixer Structure

The specific design of the planar B-spline micromixer structure is shown in Figure 2. The height (z) and width of obstacle dimensions are 200 µm and 500 µm and the length of the mixing channel is 40 mm and fixed for the optimized microchannel. The T inlet channel width and length are also set for the optimized microchannel of 10000 µm and 600 µm, the mixer depth being 1000 µm. The design of planar B-Spline micromixers with 20 same chambers and obstacles with shapes including straight respectively. Figure 3 shows the designer and comparison of a 3D basic planar micromixer with obstacles for the planar channel micromixer. The micro-mixer dimension is shown below in the area with surface grooves and a computing area for the second structured system.

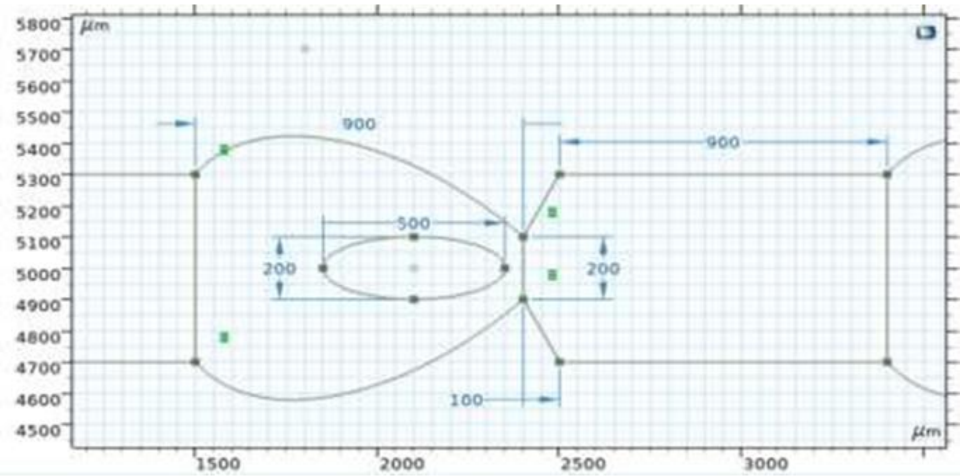

Figure 2: B-spline structure model

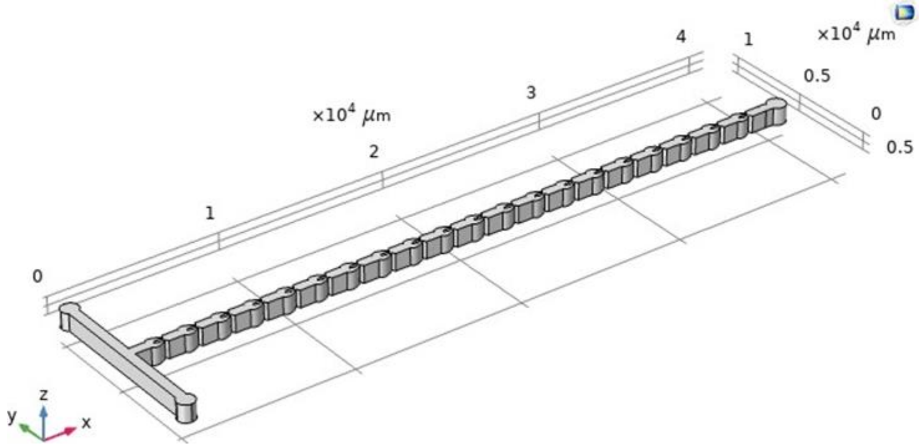

Figure 3: 3D planar B-Spline micromixer with geometric design from the top view

2.2 Planar Tesla Micromixer Structure

Figure 4 shows the design and dimension of the planar micro-mixer with the Tesla structure. The barrier's height (z) and width (w) were 400 µm and 800 µm, respectively, and the mixing channel's length was 40 mm and fixed for the optimum microchannel. The T intake channel's width and length are also fixed for the optimal microchannels of 10000 µm and 600 µm respectively, and the mixer depth is 1000 m. Figure 5 shows the 3D design of planar tesla structure micromixers with 13 spaces and barriers, including their respective straights. The literature review shows greater mixing performance in a microchannel of unidirectional design. Therefore, it was built with asymmetrical barriers.

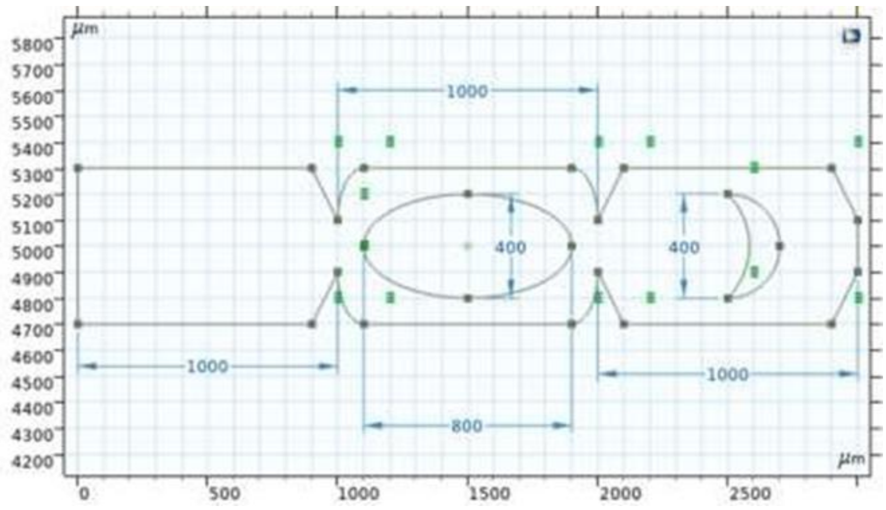

Figure 4: Tesla structure model

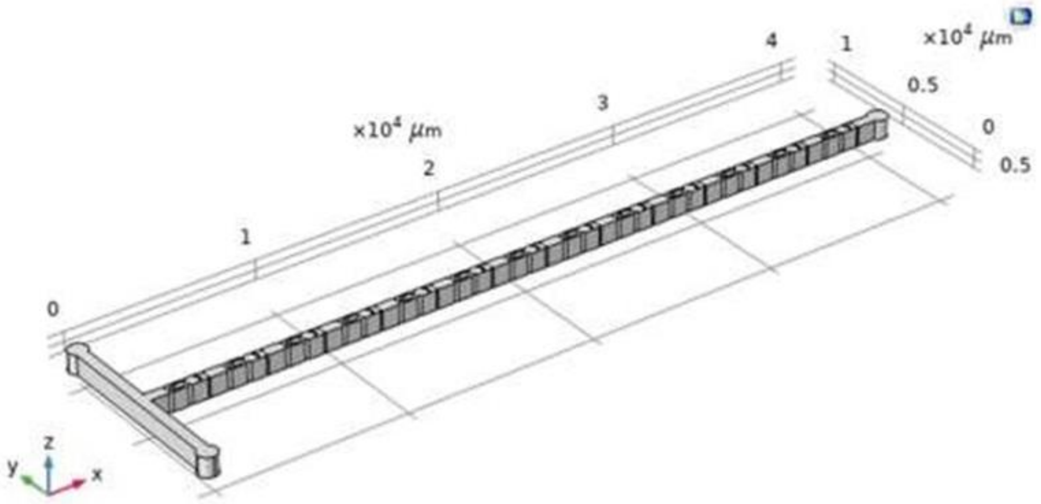

Figure 5: 3D planar Tesla micromixer with geometric design from the top view

2.3 Equations

The inertial effects of the relative, as opposed to the viscous effects known as the Reynold Number, were calculated using a dimensionless figure, as shown in Eq. 1.

$$Re= \frac{\rho UL}{\mu} = \frac{UL}{v} \qquad \textit{Eq. 1}$$

Where is the fluid density, U is the flow's characteristic velocity, μ is the fluid viscosity, and L is the device's characteristic dimension. When the fluid is laminar, the flow of a fluid with Re > 1 appears to be turbulent.

3. Results and Discussion

3.1 Mixing of basic planar micromixer

Figure 6 shows the concentration mixing for the basic planar micromixer, as well as an analysis of the mixing performance of each planar micromixer design. For the mixing of basic planar micromixer, it depends on diffusion therefore a modified microchannel geometry is needed for the solution to fully mix. For the mixing in planar B-spline micromixer structure, it is observed that it has a better mixing in comparison with the basic planar micromixer. The mixing happens at the starting of the channel. The mixing process is completed as the output is green and the mixing at the end of the channel is achieved.

Based on the observation for the planar Tesla micromixer, the mixing was also achieved through the channel. The colour red and blue seems to change in their path. The mixing process is complete because at the end of the channel green colour of the solution occur on streamline colour viscosity result.

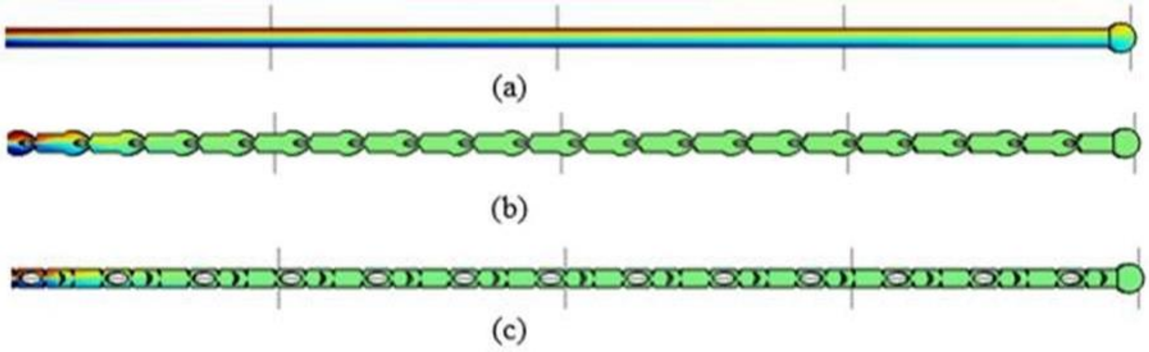

Figure 6: Colour intensity of (a) basic planar micromixer, (b) planar B-spline micromixer (c) planar Tesla micromixer

3.2 Analysis of basic planar micromixer

Figure 7 demonstrates a plotted graph of the standard deviation value for concentration mixing in a basic planar micromixer. The result shows that the fluids are not mixed at the channel output. The standard deviation of concentration is not close to 0, indicating that the solution is not thoroughly mixed. The standard deviation is observed to be 1.03173 at the end of the mixing channel. This quantitative measurement shows that for the fundamental basic planar micromixer, modifications to the geometric design along the channel need to be implemented to achieve complete fluid mixing.

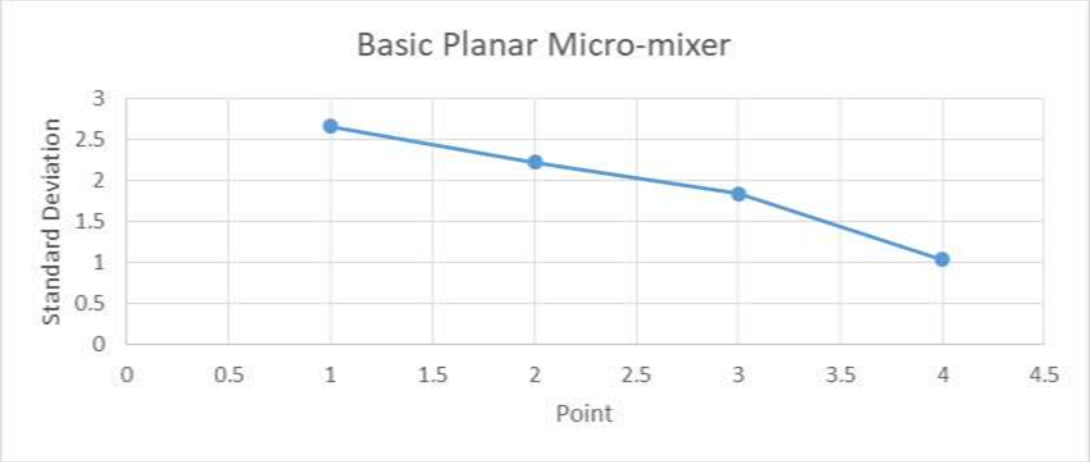

Figure 7: Viscosity's standard deviation vs. point of basic planar micromixer

3.3 Analysis of planar B-spline micromixer

Figure 8 shows the plotted graph result of the viscosity's standard deviation value for concentration mixing in the micromixer. The standard deviation value in a planar B-spline micromixer can be seen to decrease significantly at mixing channel point 1, where the value drops from 0.026684 to 0. This observation shows that the fluids are fully mixed and achieved 0 value at the end of the channel. Planar B-spline micromixer design with structure and obstacle inside is achieved the mixing earlier at point two, and this design can achieve complete mixing in channel length until the end of the point. This shows that the mixing is better than the mixing in basic planar micromixer and the mixing in planar B-spline micromixer with structure inside would result in the mixing of two solution to be completely mixed.

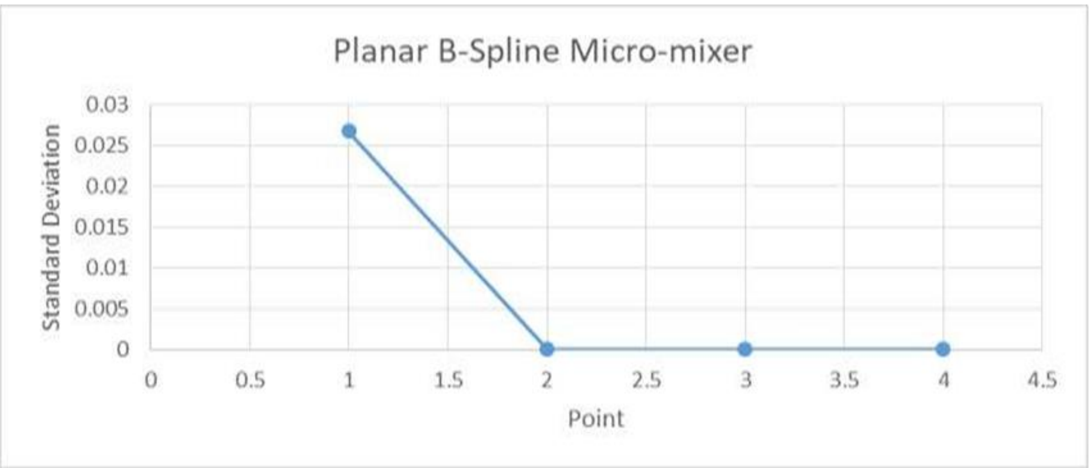

Figure 8: Viscosity's standard deviation vs. point of planar B-spline micromixer

3.4 Analysis of planar Tesla micromixer

Figure 9 shows the plotted graph of the result of viscosity's standard deviation of the fluids viscosity colour intensity versus the channel mixing length or the number of the points. Based on the observation, it shows that the result viscosity's standard deviation of the fluids viscosity color intensity versus the channel mixing length or the points. Based on the standard deviation viscosity graph, the planar Tesla micromixer designs show that the fluids are fully mixed and achieved 0 value at the third point of the channel and it shows that the mixing is better than the basic planar micromixer design. For a better and increase mixing time in planar Tesla micromixer, the mixing can be improved by suitably designing geometric parameters of the groove, such as the depth, the width, and the oblique angle.

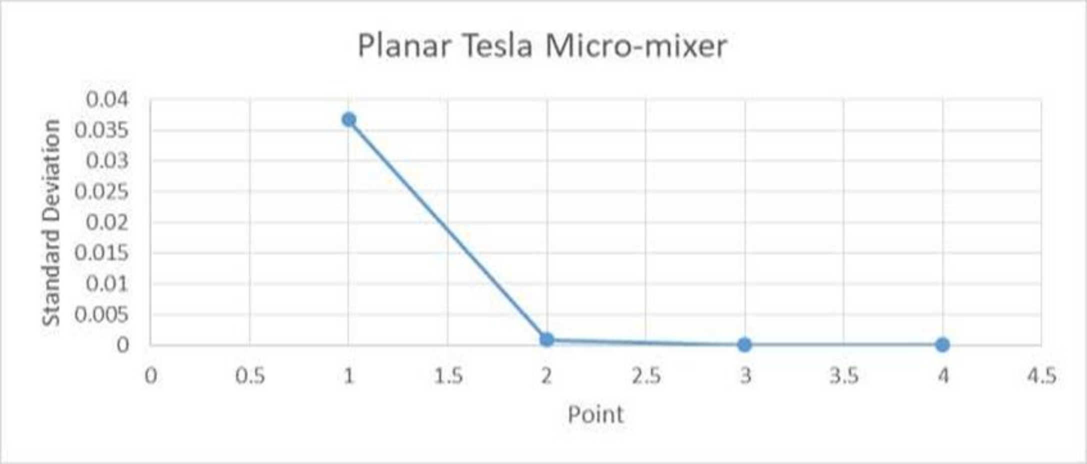

Figure 9: Viscosity's standard deviation vs. point of planar Tesla micromixer

3.5 Comparison planar micromixer design

Figure 10 shows the comparison in the concentration's standard deviation of planar micromixer design. From the graph observation, the mixing performance in basic planar B-spline micromixer shows higher mixing performance when compared to planar Tesla micromixer, both of the planar micromixer design has a good mixing performance as the standard deviation value for both micromixers started to decrease significantly when it reaches the mixing channel at point two and three. Planar B-spline micromixer design have a better and higher mixing performance than the planar Tesla micromixer which both mixing compared at point two and three. Comparison of standard deviation of each micromixer is shown in Table 1.

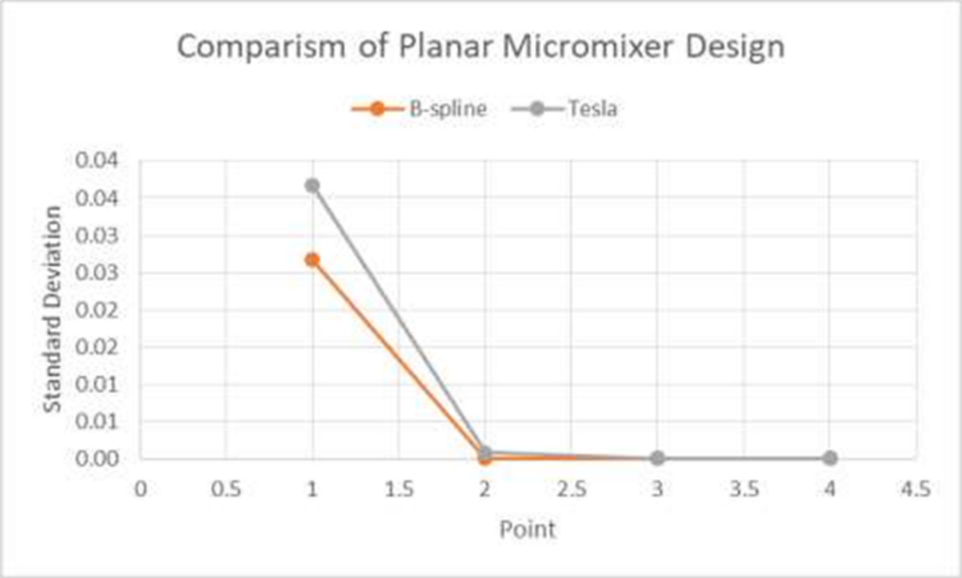

Figure 10: Comparison of concentration's standard deviation value for planar B-spline and Tesla micromixer design

Table 1: Comparison of standard deviation of each micromixer

Type of planar micromixer	Standard Deviation
Basic	1.03173
B-spline	0
Tesla	0

4. Conclusion

It can be concluded that by optimizing the design of the basic planar micromixer, the micromixer mixing performance may be enhanced, as the standard deviation value is close to 0, indicating that the data points are approximately equal to the mean value. For the basic planar micromixer, it shows that modification of the geometry channel inside the mixer is needed for the mixing to be completed as the mixing is done by only diffusion. With the optimization in the design geometric parameters of the groove, such as the depth, the width, and the oblique angle, it shows a better mixing performance as the mixing is by diffusion and chaotic advection when compared to a basic planar micromixer. The standard deviation value of each simulation of the planar micromixer design is obtained for comparison of mixing performance.

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