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Design and Simulation of Passive Micromixer in Microfluidic Device

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Abstract: Microfluidic device can be used in numerous fields as its capabilities in fluid mixing on Lab-On-Chips (LOC). The usual mixture between two liquids is to use a passive micro-mixer straight channel. This method is able to mix between the two liquids but for an existing design, a straight channel micro mixer takes time for micro-mixing diffusion. The main purpose of this project is to design passive micromixer and simulate the design in order to analyse the mixing rate. In this paper, three different passive micromixers were evaluated based on the patterns of Y-shaped micromixer. The micromixers are basic straight micromixer, grooved micromixer, and repetitive meandering micromixer. The simulation of micromixer designs were mainly done and analysed in COMSOL Multiphysics, a widely used modelling and simulation software for microfluidic devices. The simulation fluids diffusion in micromixers was determined by the results of concentration's standard deviation values along the mixing channel width and length of 100μm and 2000μm respectively. The evaluation data of designs comparison shows that repetitive meandering micromixer design was proven as the best model as it attained complete mixed fluids amongst other micromixer designs as it achieved the standard deviation value of 0 faster than other designs.

Keywords: Micromixer, Microfluidic Device, COMSOL

1. Introduction

Micro-electromechanical System (MEMS) is a process technology used in the manufacture of small integrated devices or systems incorporating mechanical and electrical components. They are produced using batch processing techniques for integrated circuits (IC) and can vary in size from a few micrometres to millimetres. MEMS microfluidic systems usually incorporate chemical analysis, drug delivery, biological sensing, environmental monitoring and many other applications. It should be noted that the form of flow (laminar or turbulent), bubble effect, capillary forces, fluid resistance and capacitance all have an effect on the final design of MEMS fluidic devices [1]. In particular, MEMS technology has made it possible to reduce the size of several types of sensors, actuators and systems

by orders of magnitude, while also enhancing the efficiency of sensors (e.g., inertial sensors, optical switch arrays, biochemical analysis systems, etc.) [2].

Micro mixer is a device that produces a mixture between two liquids. The result of the mixture being effective or not depends on the geometry, width, length and obstruction of the micro mixer. There are two types of existed micro mixer which are knows as active and passive micro mixer. The term 'active micro mixer' refers to a microfluidic system in which the application of some form of external energy disturbance improves the mixing of species. Active mixers reported in the literature use a variety of phenomena, such as electrokinetic instabilities, magnetic stirring, magnetohydrodynamic effects, and acoustic microstreaming actuation [3]. Passive micro mixers also called static micro mixers are based on the structure of the microchannels to enhance molecular diffusion and chaotic advection for efficient mixing. According to the dimensions of the structure, passive micro mixers can be sub-classified as either three-dimensional (3D) or two-dimensional (2D) [4].
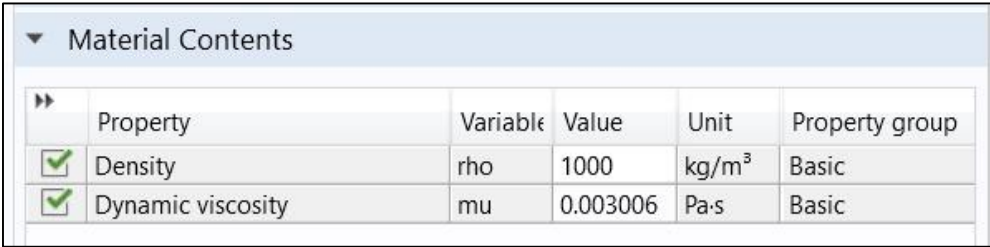
The usual mixture between two liquids is to use a passive micro-mixer straight channel. This method is able to mix between the two liquids but for an existing design, a straight channel micro mixer takes time for micro-mixing diffusion [5]. Due to the time consumption in order to mix liquids, this issue can be solved by modifying the geometry design of the micro mixer so that the mixing process will be faster and less time consuming.

2. Materials and Methods

The purpose of design modelling, device modelling and processes in various fields such as engineering, manufacturing and scientific research can be done by using simulation software such as COMSOL Multiphysics. It has the capabilities of fully coupled multiphysics and single-physic modelling, while giving the advantages of a complete modelling workflow which is the process from creating geometry until the post-processing.

2.1 Materials

Microchannel concentration mixing can be achieved by incorporating a set of simulation parameters which govern the fluid flow, fluid composition, etc. A set of physical interfaces has been combined within the developed micromixer designs in order to test the simulation model. The physical properties for the fluid participating in the simulation model are shown in Figure 1. The properties are similar to the fluid properties of blood. Blood is a commonly used fluid in micromixer for various basis in medical field. Both of the inlets were assigned with the same flow rate of $1.5 \times 10^{-14} \, m^3/s$. This condition is applied to all of the micromixers and the outlet was set to fixed pressure boundary condition for analysis comparison.

|	Property	Variable	Value	Unit	Property group
☑	Density	rho	1000	kg/m³	Basic
☑	Dynamic viscosity	mu	0.003006	Pa·s	Basic

Figure 1: Physical properties of fluid

2.2 Methods

The purpose of design modelling, device modelling and processes in various fields such as engineering, manufacturing and scientific research can be done by using simulation software such as COMSOL Multiphysics. It has the capabilities of fully coupled multi-physics and single-physic

modelling, while giving the advantages of a complete modelling workflow which is the process from creating geometry until the post-processing.

The whole process from creating the geometry until the post-processing has been divided into a few phases as shown in Figure 2. It starts with pre-processing phase, which it is used as the early setup for creating a new model. Then, the processing phase which includes the process of designing a geometry, material setup, boundary condition setup, mesh development and solver setup. Lastly, the post-processing phase, it can present the analysis for the developed design and setup during early phases. Mixing in passive micro mixers relies primarily on chaotic advection realised by manipulating the laminar flow in microchannels or molecular diffusion, increasing the contact surface and time between the various fluid flows due to the dominant laminar flow on the microscale [6].
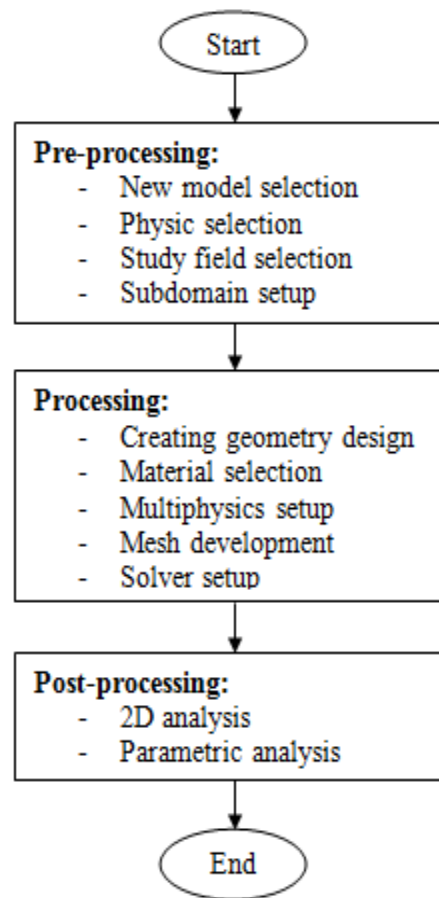

Figure 2: Flow chart of design development

In order for completing all the proposed designs, a basic Y-shaped design were created first, then it will be modified by adding the patterns or obstacles at the mixing channel. The scale values of the length unit of the model are set at micrometre (μm). Figure 3 shows the proposed models for this project which displayed the basic straight design, added grooved patterns and repeated meandering patterns throughout the mixing channel.
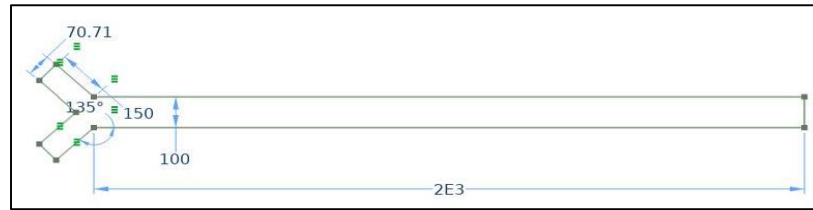
(a)
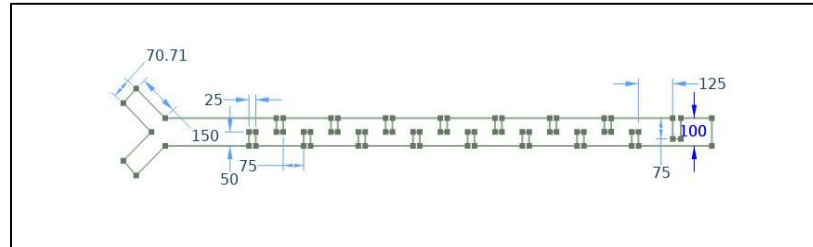
(b)
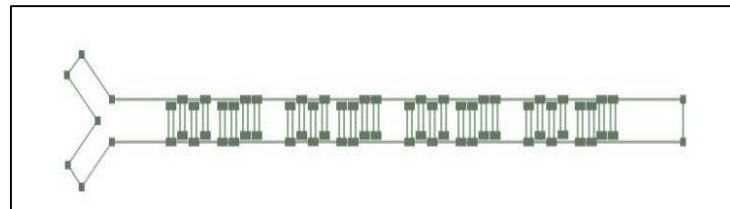
(c)

Figure 3: Geometry specification for (a) basic Y-shaped micromixer, (b) grooved Y-shaped micromixer and (c) repetitive meandering Y-shaped micromixer

2.3 Equations

The method of Computational Fluid Dynamics (CFD) is used to address the flow and transport domains in microchannels numerically. Navier-Stokes equations are used to solve and simulate the flow of fluids in micromixers. Equations (1) until equation (3) show the isothermal, non-reactive and incompressible fluids without gravitational impacts [7,8]. The equation has a set of parameters such as $p, \rho, \mu, \boldsymbol{u}, D$ and c which indicates the pressure(Pa), density (kg/m^3), dynamic viscocity $(Pa.s)$, velocity vector(m/s), molecular diffusion constant (m^2/s) and concentration (mol/m^3) respectively. To calculate the mixing fluid, the concentration's standard deviation is taken into account as shown in equation (4) [7].

$$\nabla.\boldsymbol{u} = 0 \qquad\qquad Eq.1$$

$$\rho\left[\frac{\partial u}{\partial t} + \boldsymbol{u}.\nabla\boldsymbol{u}\right] = -\nabla P + \mu\nabla^2\boldsymbol{u} \qquad\qquad Eq.2$$

$$\frac{\partial c}{\partial t} + \boldsymbol{u}.\nabla c = D\nabla^2 c \qquad\qquad Eq.3$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_i^* - \overline{C_i})^2} \hspace{3cm} Eq.4$$

3. Results and Discussion

This section discussed on the output result from the simulation that has been done in COMSOL Multiphysics in terms of the mixing efficiency. This section also described the mixing reaction inside the 2000 μm mixing channel for the basic Y-shaped micromixer, grooved Y-shaped micromixer and repetitive meandering Y-shaped micromixer.

3.1 Mixing analysis of micromixers

Based on the colour mixing in the simulation result, the analysis investigated in between different concentration of a fluid with a density of $1000\ kg/m^3$ and dynamic viscocity of $3.006 \times 10^{-3}\ Pa.s$. The mixing result can be analyzed by the visual colours in the results. A green colour indicated as full mixing, while if fluid is not mixing fully, the colour of green and yellow will be shown.

Figure 4 presented the proposed micromixer designs in this project which are named as basic Y-shaped micromixer, grooved Y-shaped micromixer and repetitive meandering Y-shaped micromixer respectively. The basic mixing channel showed that the diffusion rate in the channel is very low as the mixing process only started in the middle of the channel. Additionally, there was hardly any diffusion happened in the mixer. The mixing channel is in a straight line, consequently, transport mechanism such as chaotic advection did not exist to improve the mixing performance. As shown in the comparison figure below, by applying stretching and folding throughout the mixing channel, chaotic fluid flow generated to enhance the diffusion of fluids. It is apparent that repetitive meandering design with multiple sets of complex patterns along the mixing channel excessively improved the mixing performance. In addition, the grooved micromixer design has a better mixing performance than the basic design, as some groove patterns added throughout the mixing channel, therefore aids the fluids diffusion inside it. It can be stated that the number of obstacles or patterns are proportional to the diffusion process.

(a)

(b)

(c)
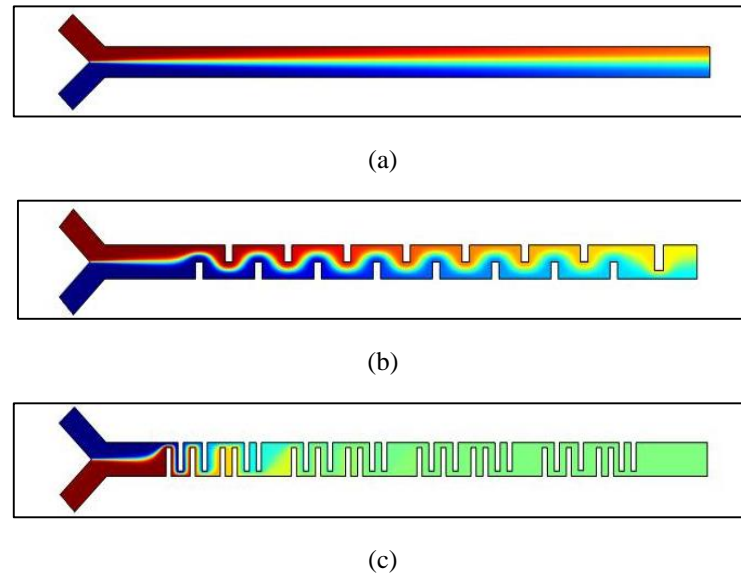
Figure 4: Concentration's colour intensity for (a) basic Y-shaped micromixer, (b) grooved Y-shaped micromixer and (c) repetitive meandering Y-shaped micromixer

3.2 Concentration's standard deviation

In order to support the 2D analysis, the concentration's standard deviation had been extracted from the 11 reference lines. Microsoft Excel is used to complete the calculation for the standard deviation. The numeric approach, a standard deviation for fluid concentration, is used in this investigation. For each step, 16 values of mixed fluids concentration are collected from the initial line of mixing channel until the end of the mixing channel which is the outlet. The evaluated standard deviations for all micromixer designs were presented in line graph as shown in Figure 5. Table 1 shows the extracted concentration's standard deviation data from the mixing channel.

Based on the graph, it is clearly presented that micromixer designs that has been embedded with patterns or obstacles are the most preferable design for a great diffusion of fluids. The mixing process generally started at step 3 for each design and the basic channel line clearly shows that it has the lowest mixing performance amongst the other design as it is gradually decreased, however did not achieve the value of 0.

Evidently, as the standard deviation of a micromixer reaches the value of 0, the fluids throughout mixing channel are diffused completely. Therefore, the best design is repetitive meandering Y-shaped micromixer as the line graph of it declined faster than basic and grooved designs. The standard deviation value of the meandering pattern design achieved the value of 0 at approximately step 7 which is in faster pace than others. Moreover, it is proven that the micromixer with multiple meandering patterns achieved fully mixed fluids upon reaching the outlet due to its standard deviation attained value of 0.

The smaller the value of standard deviation means the higher the mixing efficiency in the mixing channel. The fluids mixing is considered has fully mixed due to every point for sample data extracted from the mixing channel has the same average concentration value, hence the value of standard deviation is equal to zero which is deemed as fully mixed.
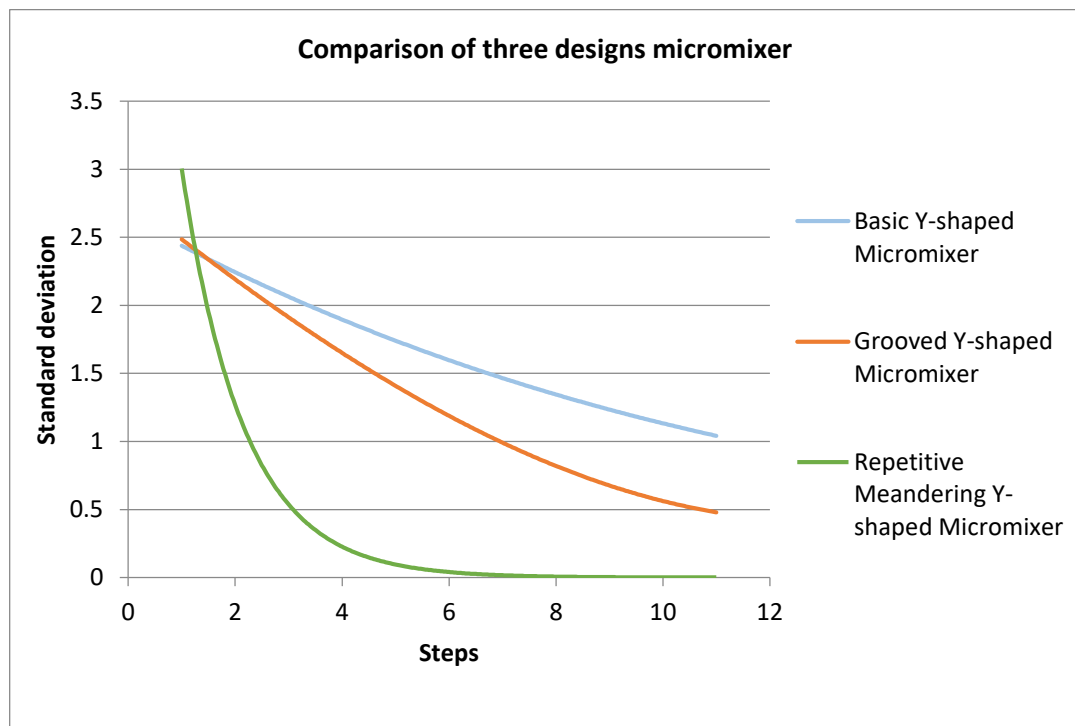

Figure 5: Comparison of concentration's standard deviation for every design

Table 1: Data of concentration's standard deviation for every design

Length (μm)	Step	Basic design	Grooved design	Repetitive meandering design
0	0	2.451563	2.447433735	2.398823423
200	1	2.251013	2.242044076	2.04925035
400	2	2.004601	1.945088908	0.512651228
600	3	1.93268	1.647349787	0.27543109
800	4	1.683339	1.337445884	0.084384273
1000	5	1.694685	1.195721533	0.049283592
1200	6	1.478253	0.994063209	0.009534794
1400	7	1.314422	0.827858802	0.0073435
1600	8	1.165893	0.700840322	0.002230482
1800	9	1.185206	0.561321306	0.000957054
2000	10	1.037033	0.468299745	0.001132901

4. Conclusion

To be concluded, the main objective of designing a micromixer is to enhance the mixing performance of fluids. These micromixers channel have a maximum length of 2000μm, width 100μm with two inlets and an outlet. The micromixers were built and modelled by using the COMSOL Multiphysics 3D Modelling software for the fluid flow mixing. The mixing performance evaluation is performed among the improved micromixers. Based on the result analysis that has been taken from basic Y-shaped micromixer, grooved Y-shaped micromixer and repetitive meandering Y-shaped micromixer, they were able to produce various mixing efficiencies on the mixing channel. Level of mixing can be increased by adding more complex obstacles or curves throughout the mixing channel.

From Table 2 below, it shows the comparison of standard deviation of each micromixer design. Higher efficiency of mixing between the designs was decided based on the standard deviation. Geometries and Reynolds numbers are intimately linked to optimal mixing performance and standard deviation at zero.

Table 2: Set of micromixers data

Type of Y-shape micromixer	Standard deviation	Mixing completion
Basic	1.03	Not complete
Grooved	0.46	Not fully complete
Repetitive meandering	0.00	Fully complete

Acknowledgement

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