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Simulation Study of Microfluidic Water Flow Velocity Using COMSOL Multiphysics

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Abstract: In microfluidic devices, the most important aspect to be considered for the manufacturing process is the geometric design. Simulation is a good approach for determining the performance of the design. In this study, several microchannels design was simulated using COMSOL Multiphysics 4.2 software in order to find the optimized geometry. It involves a study of different shape, diameter, length, and angle of microchannels design, and its influence on the water flow velocity. From the simulation results, an optimized microfluidic design was obtained consists of 1000 µm channels diameter, 1000 µm inlet channel length, 1.0 cm outlet channels length, and 110° inlet channel angle with water flow velocity of 2.3cm/s. It is expected that this optimized design will produce the same outcome when fabricated as a real microfluidic device.

Keywords: Simulation, microfluidic, microchannels, water, flow velocity

1. Introduction

In the engineering of microfluidic devices, the need clearly exists for good modeling to avoid the expensive pitfall of iterative trial-and-error based design [1]. The design and the process control of microfluidic device involved the impact of geometrical configurations on the dimension, pressure, and velocity distributions of the fluid on micrometer (10^{-6} m) scale [2]. In order to fabricate such micro devices effectively, it is extremely important to optimize the geometry of the microchannels since their behavior affects the transport phenomena in the microfluidic applications.

Because the field of microfluidics is a relatively immature field, numerical simulations of microfluidic systems can be extremely valuable both in terms of providing a research tool and as an efficient design and optimization tool. By incorporating the complexities of channel geometry and fluid flow rate into a numerical model, the behavior of a particular system can be predicted when an intuitive prediction may be extremely difficult. Due to this fact, this study was focus on the simulation of flow velocity for water in several microfluidic model based on different design, diameter, angle, and length.

2. Methodology

The simulations of the microfluidic water flow were done using COMSOL Multiphysics Modeling and Engineering Simulation Software version 4.2a. The simulation was performed according to a specific setting as described in Table 1.

Table 1 Microfluidic water flow simulation setting in COMSOL Multiphysics 4.2a

Setting	Details
Space dimension	3D
Physic	fluid flow, single phase flow, laminar flow
Study type	Stationary
Material	Water, liquid

The simulation used water as the sample fluid and the laminar single phase fluid flow interface as the model physic. Then, result visualization menu in COMSOL was being used to calculate the velocity field and the pressure field referring to the position of water surface.

Several microfluidic models were studied in order to find the optimize performance for the microfluidic design. The overall simulations involve a study of different shape, diameter, length, and angle of microchannels design, and its influence on the water flow velocity.

3. Results and Discussion

From the study, several models of microfluidic were drawn and simulated. Each model had produced helpful information in optimizing the water flow velocity. The initial study was performed using the model shown in Fig. 1. The initial model in Fig. 1 consists of one inlet channel and one outlet channel. It was simulated to find the optimize diameter and inlet channel's angle.

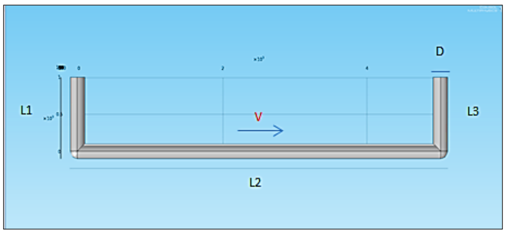

Fig. 1 Microfuidic simulation model for optimizing microchannel's diameter and angle

Table 2 Water flow simulation result of Fig. 1 model design for different diameter

Diameter (µm)	Inlet angle (degree)	Velocity (m/s)
200	90	1.10 x 10^{-3}
500	90	5.10 x 10^{-3}
1000	90	0.0082

Table 3 Water flow simulation result of Fig. 1 model design for different inlet angle

Diameter (µm)	Inlet angle (degree)	Velocity (m/s)
1000	90	0.0082
1000	100	0.0084
1000	110	0.0085
	120	0.0083

From the simulation results of in Table 2 and Table 3, it shows that microchannel's diameter of 100µm and angle of 110° produced the highest water flow velocity. Based on this preliminary result, more complicated model as shown in Fig. 2 and Fig. 3 were drawn and simulated.

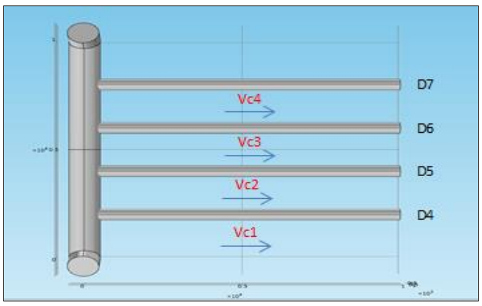

Fig. 2 Microfuidic simulation model with four outlet channels

The model design in Fig. 2 consists of one inlet channel and four parallel outlet channels. Simulation was done in order to find the water flow velocity in each outlet channels (V_{c1}, V_{c2}, V_{c3}, and V_{c4}).

Table 4 Water flow simulation result of Fig. 2 model design

Channel	C1	C2	C3	C4
Velocity (m/s)	0.006	0.004	0.0025	0.0014

From the simulation result in Table 4, it shows that the model design in Fig. 2 had produced high water flow velocity but, it was not uniformly distributed for each outlet channels. This problem was solved by implementing the meiosis like design in Fig. 3 which consist of a single inlet channel and diverged into four outlet channels.

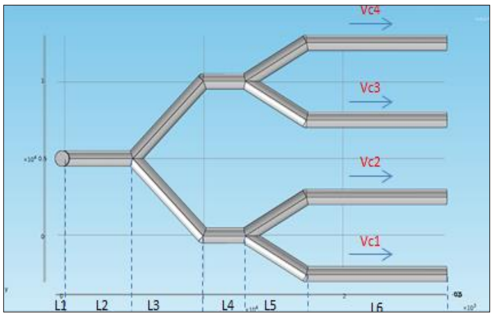

Fig. 3 Microfuidic simulation model with four outlet channels (Model 3)

Table 5 Water flow simulation result of Fig. 3 model design

Channel	C1	C2	C3	C4
Velocity (m/s)	0.0023	0.0023	0.0023	0.0023

The water flow simulation result in Table 5 shows that microfluidic design in Fig. 3 produced high and uniform water flow velocity for each channel. Based on this finding, this model is considered to be the optimized design. This design consists of 1000 µm channel's diameter, 1000 µm inlet channel's length, 1.0 cm outlet channel's length, and 110° inlet channel's angle. Even though the microchannels diameter of the optimize geometry is up to 100µm, it is still acceptable because Bayraktar (2006) had mentioned that the characteristic dimension of microchannels within a microfluidic system is in the range of 1-1000µm [3].

The optimized design produced high and uniform water flow velocity which is 2.3cm/s for each outlet channels. The flow velocity obtained is considerably up to date with current microfluidic development. Stone (2001) had also mentioned that the flow speeds/velocity for liquids are possibly in the range up to cm/s which yields a Reynolds number less than 30 [4]. The uniformity of flow velocity at each channels are also important when integrating the microfluidic device with sensing elements for accurate measurement. It is crucial in several application including sensor and detection for having high and uniform flow velocity in parallel microchannels. Siegrist (2010) had explained that in the development of microfluidic systems, it is often necessary to achieve complete, uniform filling of microchannels, such as those needed for nucleic acid amplification or detection application [5]. Solovitz (2013) also mentioned that for unbiased readings, the flow rate in each channel should be approximately the same [6].

4. Summary

Findings of simulation analysis for microfluidic water flow velocity with several designs have been reported in detail. This study had produced an optimized microfluidic design with an acceptable channel diameter and high water flow velocity. It is expected that this optimized design will produce the same outcome when fabricated as a real microfluidic device.

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