An Example of Passive Micromixer Design, Simulation and Optimization

Biomedical engineering MSc Thesis

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Abstract— **The paper presents the designing process of the passive micromixer. Design parameters of microfluidic channel's geometry are optimized based on flaw simulation results. CAD software Solid Works and application Flo Xpress are used for designing and simulation. The part of MSc Thesis is given here in order to show outcome ability of Biomedical department student.**

Keywords- Passive Micromixer, Design, Optimization, Simulation

I. INTRODUCTION

Department for Biomedical Engineering encourages the multidisciplinary approach in research and teaching segments of students educational process. Basics of Micro/nano engineering Micro and Nano fluidics are two elective courses that offer bases for micromixer design and fabrication. Work on MSc thesis "Passive micro mixer based on Tesla's valve" starts with design and two directions flow simulation of Tesla's valve. An idea to design new passive mixer as modified Tesla's valve leads to optimization of functional geometry based on simulation results. Eventually, the fabrication of passive mixer is done by 3D printing process.

Part of MSc thesis done by Sinisa Rankovic, student of Biomedical module and supervised by assistant professor Bozica Bojovic is presented in the paper. Independent and self-supporting work in software Solid Works and application Flo Xpress Wizard for designing and simulation are given here in details for three design variation of the passive micromixer.

II. BACKGROUND

A. Passive Micromixer

Microfluidic systems are designed to transfer very small quantities of fluid, such as microliters or even nanoliters within the device. These microfluidic systems are part of Lab-on-Chip devices that often testing using chemical, electrical, or optical sensors for biomedical diagnostics outside the traditional medical laboratory. In micro channels the Reynolds number is very small, which implies laminar flow. A variety of micromixers that enhance mixing performance are reviewed in [1]. Micro mixers are categorized as either active or passive. Active micromixers use external energy is applied for liquids perturbation. Passive micro mixers consist of specially designed micro channel configuration which increase contact area of liquids and reduce size of micro fluidic channels.

In order to produce turbulent instead of laminar flow, the passive micromixers use multiple splitting and reunification of the fluids. Therefore, passive micromixers apply both convection and diffusion mixing concepts. In this paper the innovative passive micromixer with embedded barriers is presented as a result of MSc Thesis work.

B. Tesla's valve

Tesla patented in1920. valvular conduit [2] designed in such way that allows fluid to flow unimpeded in one direction (in Fig. 1 shown as dotted line from right to left side), but blocked in the other direction (in Fig. 1 shown as dotted line from left to right side). In scientific papers that have been found in literature, Tesla's valvular conduit is considered as a one way valve that has no moving parts [3, 4].

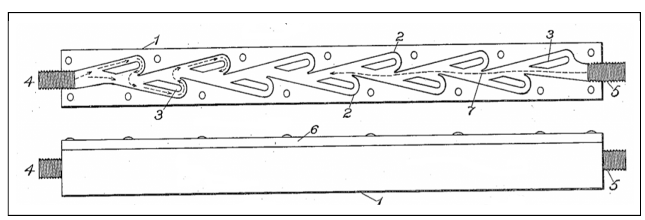

Figure 1. Top and side view of Tesla's valve [2]

This type of valve with no moving parts is preferred in microfluidic systems as micromixer due to its simplicity of design, operation and maintenance. Also, this kind of planar micromixer is not so difficult to fabricate using methods of micro fabrication such as micromachining, soft lithography or 3D printing.

III. Design and Simulation

Nikola Tesla had unique method of engineering, which is quite similar to actual computer aided design and simulation. Instead of computer, he performed the mental simulation. He stated in [6]: “My method is different. I do not rush into actual work. When I get an idea, I start at once building it up in my imagination. I change the construction, make improvements and operate the device in my mind. It is absolutely immaterial to me whether I run my turbine in thought or test it in my shop. I even note if it is out of balance.”

Today we ought to use Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD) to “look inside” the micro fluidic system to see how it actually worked and improve them before manufacturing. This approach was applied for micro mixer design, simulation and optimization process.

The design requirements were to decrease micromixer length and provide good mixing ability in same time. The simulation are performed using Solid Works Flo Xpress application for fluid dynamics that calculates how fluid flows through micromixer. Based on the calculated velocity field, the channel’s geometry is optimized.

The mixing process in passive type of micromixer with simple longitudinal channel is diffusion through the contact surfaces of the fluids in the channel. It’s very slow process and require very long micro channel. In order to improve mixing in the channel the obstacles have to be added and shapes of walls may be changed. This is the manner which reduces the mixing time by increasing the velocity of fluids due to channel’s cross-section reducing.

In this paper the so-called chaotic advection is induced using obstacles at walls and barrier in channel. Advection may cause the transversal component of the fluid flow. This transversal flow of fluid increases the contact surface which improves mixing. Achieving transversal fluids flow is possible by changing the form of micro channels that stretches, shrinks, bends and leads to splitting laminar flow. When collision with obstacle changing the fluid flows that could cause the appearance of vortices and leads to transversal mixing.

In order to simulate fluids flow and observe mixing, we have to set the basic parameters such as mass flow, pressure and coefficient of gravity. Also, it is assumed that all the walls with which the fluid comes into contact is ideal. During simulation, the mixing of Newtonian and non-Newtonian fluids is not supported in Solid Works Flo Xpress application. Therefore, in the simulation, we could not mix the blood and water, as preferable application in biomedicine. For our simulation, we decided to combine the two Newtonian fluids, the water, as the most abundant and the alcohol, as frequent reagent in biological assays.

IV. Results and Discussion

Famous phrase arranged in USA: “A picture is worth a thousand words”, or Chinese proverb “One picture is worth ten thousand words” is engaged here to explain results of passive micro mixer simulation.

Preliminary design is the expression of a creative “aHa” thought. The first design is shown in Fig.1-top view. This passive micromixer is composed of three central barriers in form of the letter V and disc-shaped channel’s walls. Since an arrangement of obstacles leads to better mixing, in Fig.1-bottom, another variation of channel’s geometry is shown.

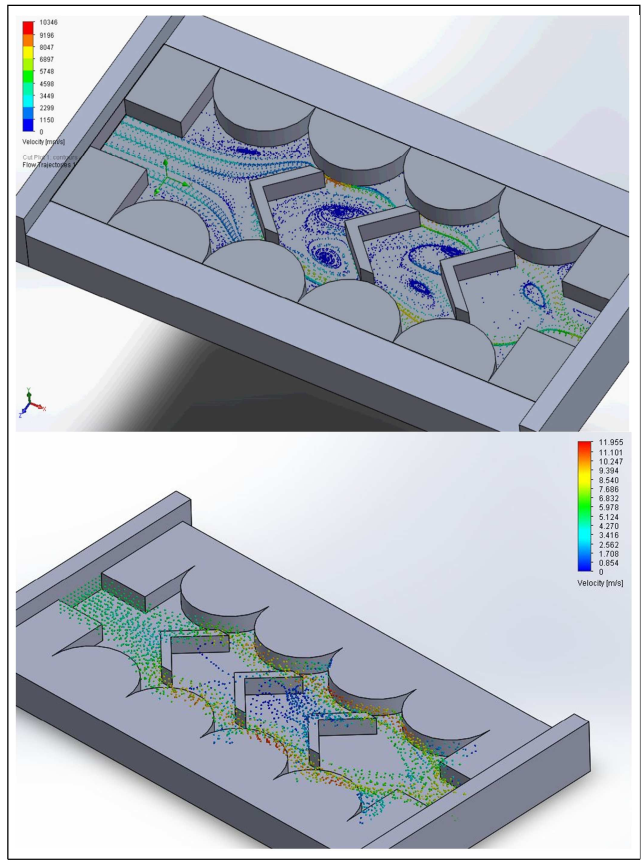

Figure 2. The first design of passive micromixer with the velocity trajectories; Top view – preliminary position of V barriers and bottom view – modified positions of V-barriers

In this case, the first V-barrier divides fluid into two parts. Since the entire mixer is symmetric, the only one stream will be explained. The space between two obstacles is occupied by swirl fluid in turbulent flow, while the rest of it has laminar flow close by microchannel’s walls.

For first design the channel’s geometry is set up in specific manner to preserve relation between features. The ends of the V-barriers are parallel to the center of the corresponding disc, while the spacing between the V-barriers is equal to the radius of the disc. The only changeable dimension is the angle legs of the V-barrier. Based on various simulations in the Solid Work's application Flo Xpress, the most efficient angle that changes the fluid flow from laminar to turbulent is 45 degrees.

Streamlines with velocity (Fig.3-top) and pressure (Fig.3-bottom) distribution are shown as Flo Xpress simulation output. Fluid inlet is on the left and outlet is on the right side. The distribution of pressure in the micromixer during this flow shows that the greatest pressure is at walls obstacle. This design shows necessity for obstacles geometry changes in order to improve flow trajectories.

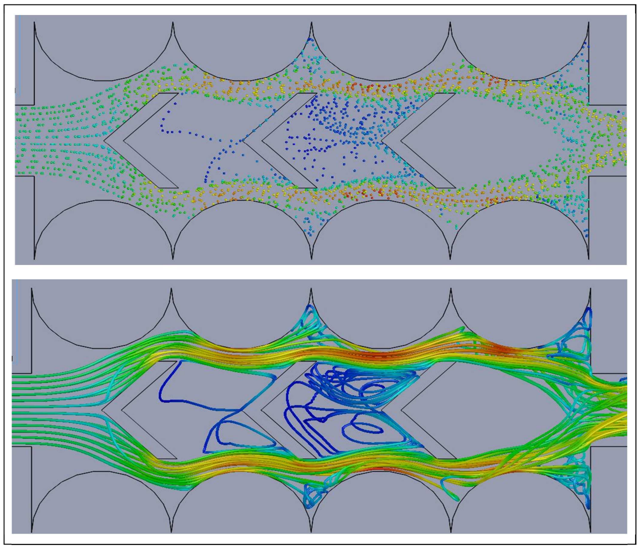

Figure 3. Flow trajectories with velocities (top view) and pressure (bottom view) distribution

For second design the flow direction is changed, so the inlet is on the right and outlet is on the left side. This design is shown in Fig.4. The changes of passive micromixer that are induced for second design are based on the need for better mixing of fluids. The entry and exit part of walls are conical in shape. The pathway of streamlines of previous design (Fig.3-bottom view) leads to this solution.

The V-shaped obstacle repulses fluid and forces it to flows nearby the channel's wall. The fluid, which is now divided into two segments flows along the walls and toward point of first V-barrier. The mid V-barrier is modified and central part is cut off, so the passage appears. This passage, like a nozzle, makes fluid accelerates and hits the next V-barrier. In the region between the two barriers, the fluid has turbulent flow and mixes with the streams of fluid which luminary flows along the walls.

Streamlines velocity distribution is presented in Fig. 4 in top and isometrics views. Segment of the fluid that flows nearby wall remains not disturbed in previous design of the passive micromixer, as can be seen in Fig.4. In order to have the even better mixing process of fluids, it is necessary to disrupt the fluid's segments that flow along a channel's walls.

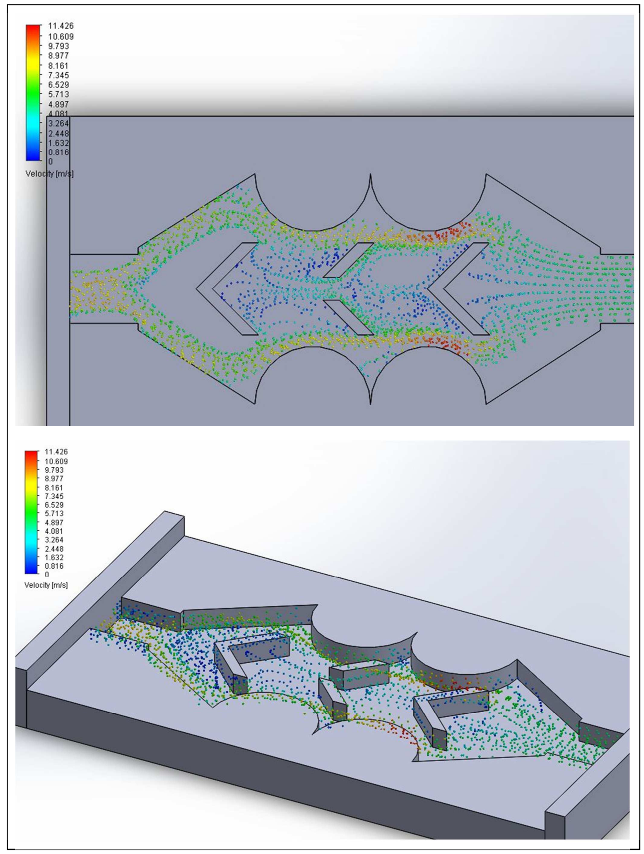

Figure 4. Top and isometric view for the second micromixer design

The new design with connected obstacles is presented in Fig.5. This idea to connect mid barriers to the channel's walls is introduced to force overall fluid to flow turbulent.

Fluid flows through slanted walls into micromixer from the left side. The contact with the first V-barrier induces turbulence in the stream. The fluid, which is now divided into two sections, flows towards the round channel's walls and directs by second obstacle to the passage in it. Since there is no other way to flow, the fluid is squeezed throughout nozzle-like passage. Reduced cross-sectional area leads to acceleration of the fluid, which can be seen in Fig.5-top view. The maximum flow velocity in this passage is 3.5 m/s.

Fluid hits the third obstacle and repulses from it and that leads to segmentation again. Fluid flows towards rounded channel's walls and streams around the last V-barrier ends. Streamlines in Fig.5 indicate turbulent flow at the rear end of passive micromixer. Bearing in mind that the fluid is divided into two streams which flow symmetrically, the collision of them appears at the micromixer outlet. This phenomenon leads to acceleration of the fluid and to mixing process. The outlet of micromixer has slanted walls, same as inlet. This is inherited from previous design.

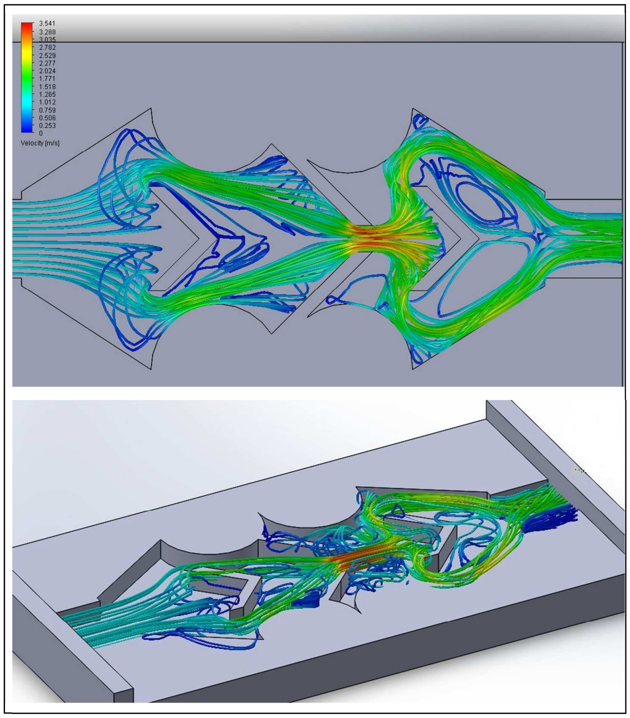

Figure 5. Top and isometric view of the third design of micromixer: the velocity streamlines

The last explained design that is shown in Fig. 5 is accepted as final. Passive micromixer with Y-type design inlet is presented in Fig.6. Legend shows percentage of two fluids that are mixing in it. Fluid inlet is on the left and outlet is on the right side.

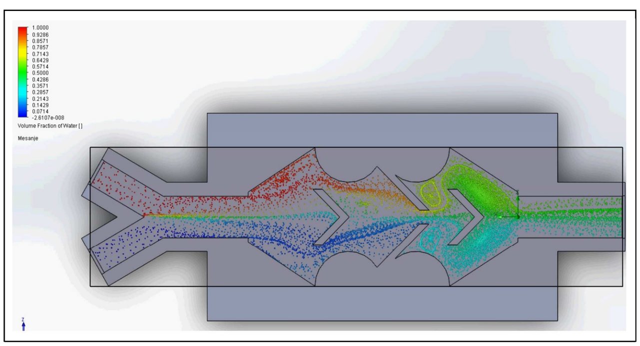

Figure 6. Top and isometric view of the third design of micromixer: the velocity streamlines

Water and alcohol are set up as two fluids for mixing simulation that is performed Flo Xpress application. Simulation output in Fig.6 shows water as red streamline and alcohol as blue one.

Two fluids flows laminar in the beginning and mixing process are perform only by diffusion in boundary area where contact is established. Yellow, green and magenta dots in left side of micromixer present that in Fig.6. First V-barrier separates two fluids towards rounded channel's walls, and afterwards to mid obstacles. The mid obstacles force fluids to stream throughout nozzle-shaped passage, after which turbulent flow are induced. This mid obstacle performs whole job of mixing and results is evident as yellow and magenta swirl in space between mid and last obstacles. Advection is phenomena that appears here and make this way of mixing efficient. Last V-barrier directs fluids towards rounded walls and cones shaped outlet. Green streamlines at the end of mixing process, outlines mixing performance of Y-type passive micromixer. It is obvious that design requirements are accomplished and efficient passive micromixer design is proposed.

V. CONCLUSION

In this paper, an innovative passive mixer has been designed and geometry of channel has been optimized regarding to simulation results. Design of passive micromixer achieves excellent mixing performance with contribution from advection process.

This particular design of passive micromixer is fabricated using 3D printer, as one of quick and cheap method for prototype. Micromixer like this could be component of micro fluidic system for inexpensive and disposable Lab-on-chip devices. Furthermore, passive micromixer can be fabricated using micro molding, micro embossing and laser engraving processes.

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