Journal of Engineering Science, Vol. 10, 73–83, 2014

Preliminary Study on the Effect of Inlet Pressure of Standard Slit Interdigital Micro Mixer Towards Mixing by Computational Fluid Dynamics

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Abstract: *The aim of this work is to visualise the velocity profile and concentration profile of the mixing element of standard slit interdigital micro mixer (SSIMM) by simulating it in computational fluid dynamic (CFD). Since the micro mixer uses pressure-driven flow as its fluid actuation, the effect of change of the inlet pressure towards these profiles is observed. These preliminary study would give the general overview of the properties of the mixing element which will contribute to further studies later on in the mixing performance of this type of micro mixer.*

Keywords: Slit interdigital micro mixer, computational fluid dynamics, inlet pressure study, velocity profile, micro mixers

1. INTRODUCTION

The number of research works on micro-scale devices in chemical engineering has increased significantly during the past years. The main advantage of the micro reactor is the high area-to-volume ratio which considerably enhances the mass transfer and heat transfer rates that offer better yield and selectivity than the conventional reactors.[1] Several researchers studied the mixing behaviour in various types of micro mixer, particularly T-shaped[2,3] and Y-shaped[4,5] micro reactors by using experimental[6–8] works or via computer simulation.

One of the micro mixers that receives a considerable attention in pharmaceutical[9,10] and liquid dispersion study[11] is the Standard Slit Interdigital Micro Mixer (SSIMM). SSIMM is an assembly of three components, and is namely a *Lithographie, Galvanoformung und Abformung* or Litography, Electroplating and Molding (LIGA) device containing the mixing element which is embedded in a two-piece housing.

The LIGA devices are made of nickel on copper (i.e., a nickel layer with microchannels on a copper base plate) or of silver. The stainless steel housing is made up of two pieces, the top and bottom plate connected to inlet and outlets (see Figure 1 and 2). The design of the mixing element is based on a layer containing 18 or 15 sinusoidally shaped fluid channels for each fluid with a width of 25 or 40 µm, respectively and a depth of 300 µm supported by a base plate (see Figure 3)[12] and it has an outlet slit length of 4000 µm and width of 60 µm (see Figure 4).

Figure 1: The photograph of SSIMM.

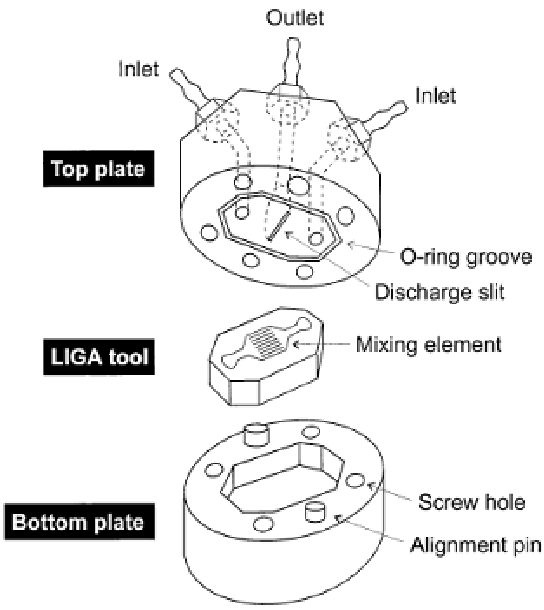

Figure 2: Explosion drawing of the SSIMM.

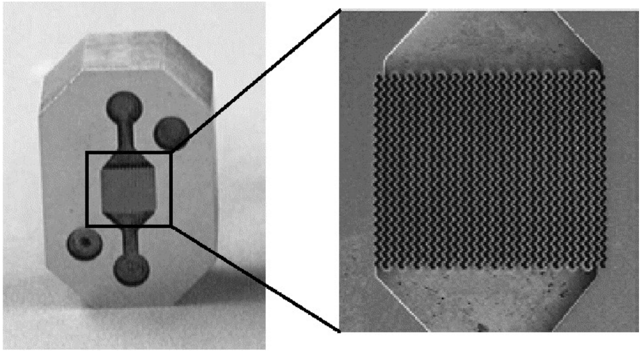

Figure 3: The mixing element.

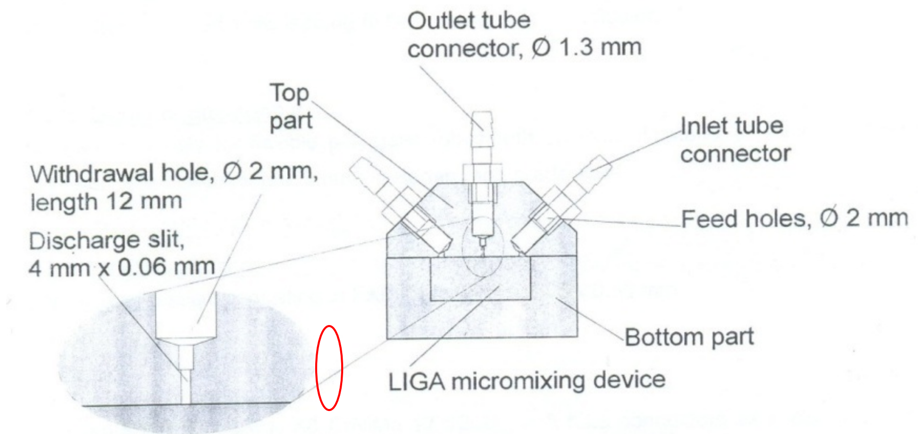

Figure 4: The schematic presentation of the assembly in the micro mixing system (Institut fur Mikrotechnik Mainz GmbH).

The objective of this work is to visualise the velocity and concentration profile along the mixing element without the presence of microchannel (the mixing element) and profiles along the outlet slit. The mixing element slot has a unique shape as the inlet is the circular form followed by a rectangular shape and the mixing chamber is trapezoidal. This type of micro mixer uses pressure-driven flow of fluid actuation where the fluid is pumped through the device inlets via positive displacement pumps such as syringe pump. The fluid flows from a higher pressure on the inlet to the low pressure on the outlet. Thus, this work presents a simulation of mixing element model of SSIMM as in Figure 5 at different inlet pressure and the resulted velocity profile and concentration profile is observed.

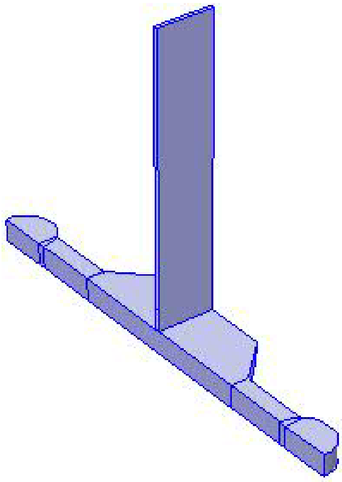

Figure 5: The model structure of SSIMM in COMSOL Multiphysics.

In this work, simplification of the actual geometry of the mixing device whereby the corrugated wall of micro channel is excluded and the mixing devices were cut in half. These simplifications were done due to the limitation of the computational power of the current setup.

2. COMPUTATIONAL FLUID DYNAMIC MODEL OF SSIMM

The mixing element inside the micro mixer is depicted as in Figure 5. The geometry of the mixing slot was built in COMSOL Multiphyisic 4.2a software based on the details given by Institut fur Mikrotechnik Mainz GmbH. There are two inlets and one outlet slit. As mentioned earlier, the geometry of the mixing device is cut in half and the microchannel corrugated wall is omitted for simplicity of the simulation and reducing high computational work. The computer work was done by using a numerical solution into solving the Navier Stokes Equation together with convection–diffusion equation.

2.1 Navier Stokes Equation

$$\rho \frac{\partial v}{\partial t} - \eta \Delta v + \rho (v \cdot \nabla) v + \nabla p = \mathbf{0}$$

$$\nabla \cdot \mathbf{v} = 0 \qquad (1)$$

In the equation, **v**, p, ρ and η denote respectively the velocity vector, the pressure, the density of the fluid and the dynamic viscosity. In the following, the norm of the velocity vector, **v**, will be noted v. The density and the viscosity data are those of water ($\rho = 1 \times 10^3$ kg m^{-3} and n = 1×10^{-3} Pa s).[13]

The system applies pressure on the inputs to drive the flow through the mixing slot to outlet at zero pressure. On the chamber wall, it is assumed to have a none slip boundary condition. Mixing is obtained by diffusion of the various species. The transfer equation is the convection–diffusion equations with a reaction term:

$$\frac{\partial C_i}{\partial t} + \nabla \cdot (-D_i \nabla C_i + C_i \mathbf{v}) = R_i \quad (2)$$

where C is the concentration, D is the diffusion coefficient and R is the reaction rate. In this model, R = 0 because the concentration is not affected by any reaction. There is a concentration of 1 mol m^{-3} on the one of the input boundary while zero concentration on the other one. At the output boundary, the substance flows through the boundary by convection.[13]

3. RESULTS AND DISCUSSION

The visualisation of velocity profile and concentration profile again the arc length are plotted as below. The arc length referring to length of mixing slot and the length of the outlet slit. The inlet pressure denoted as p0 is varies from 10 Pa to 40 Pa. The velocity and concentration profile at different pressures are shown in Figures 5–11 on the next page.

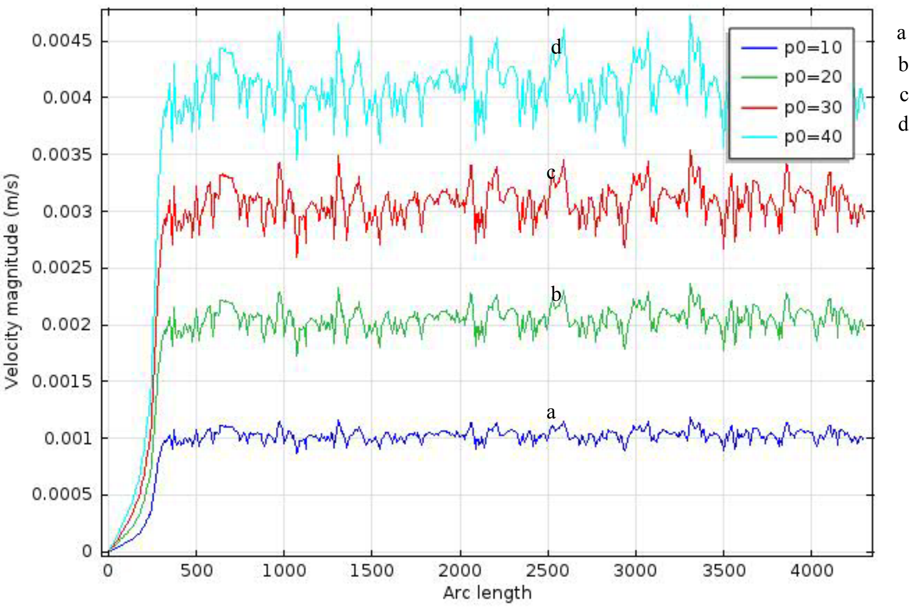

Figure 6: Velocity profile along the outlet slit.

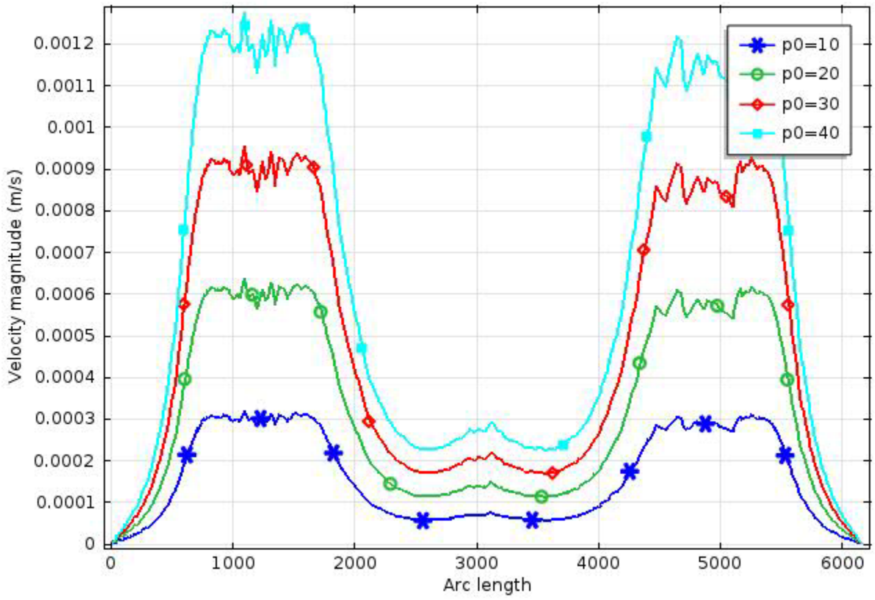

Figure 7: Velocity profile in mixing element.

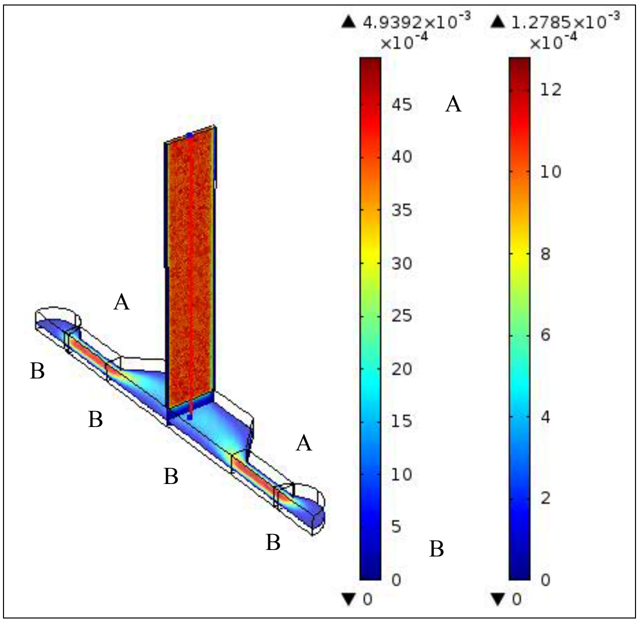

Figure 8: Velocity gradient of overall mixer.

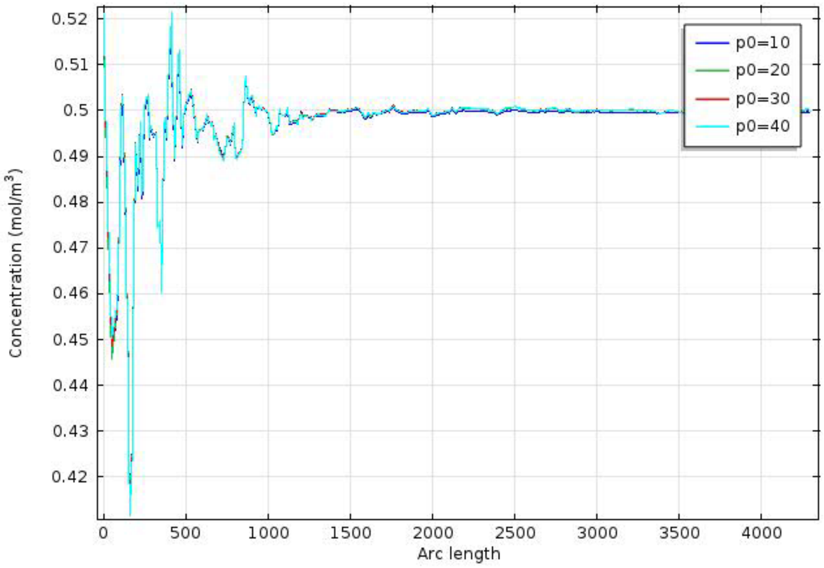

Figure 9: Concentration profile along the outlet slit.

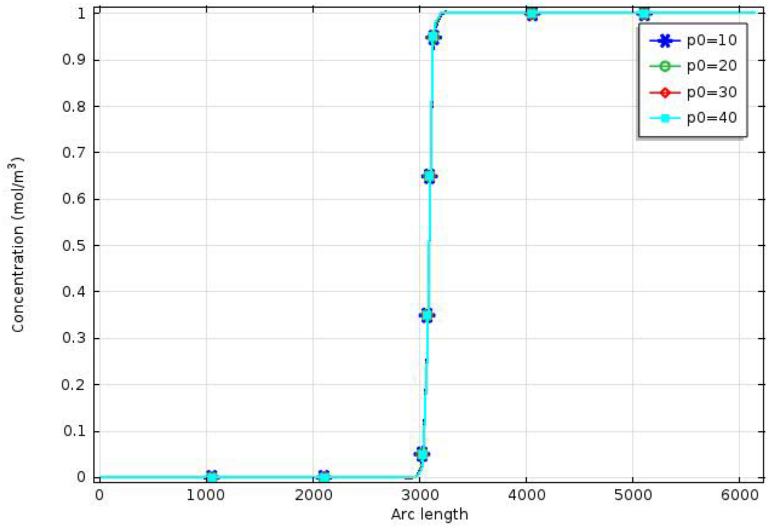

Figure 10: Concentration profile in mixing element.

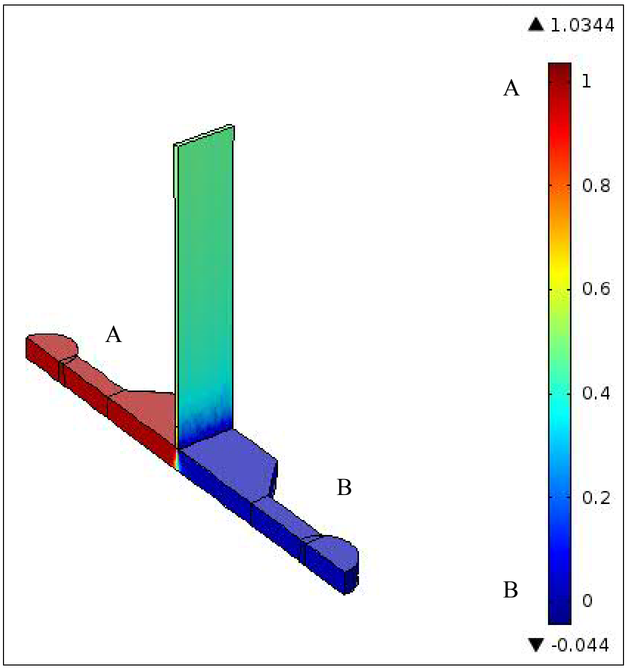

Figure 11: Concentration gradient of overall mixer.

3.1 Velocity Profile

The velocity profile along the outlet slit and mixing element without microchannel for different inlet pressure can be seen in Figure 6, 7 and 8. The outlet slit has higher velocity for higher inlet pressure as in Figure 6. It can be seen that as the inlet pressure is increased from of 10 Pa to 40 Pa, the velocity increases from 0.001 m s^{-1} to 0.004 m s^{-1}. Also, the variation of the velocity along the line is higher for higher inlet pressure which can be seen in Figure 6. As compared to velocity profile within the mixing element in Figure 7, the velocity profile shows two consecutive peaks of velocity.

The inlet 1 is at arc length equal to zero while the inlet 2 is at arc length equal to 6250 microns. The velocity of both inlets is increased and reduced as shown in Figure 8, the red area (marked A) represents the higher velocity or peaks as shown in Figure 7 while the blue colour (B) represents the lower velocity. The change of inlet pressure gives a higher magnitude of velocity but the same pattern of the velocity profile. This visualisation of the velocity profile is expected to change if the corrugated microchannel is included. The smooth line will not be as it is when stratified flow, vortex flow and engulfment flow might occurred as the fluid passes through the corrugated wall. These considerations will be taken into account in full simulation study of the micro mixer since the mixing is also being affected by this three type of flow.[2]

3.2 Concentration Profile

The concentration profile along the outlet slit and mixing area for difference inlet pressure can be seen in Figure 9, 10 and 11. The changes of inlet pressure do not have significant effects toward the concentration profile as the line overlaps with each other as in Figure 9 and Figure 10. The pattern of the concentration profile for all the values inlet pressure is the same. However we can observe that the concentration along the outlet slit is varies from 0.40 mol m^{-3} to 0.55 mol m^{-3}. This variation occurs at the arc length of outlet slit less than 1500 microns as in Figure 9. In this region, the mixing of the two concentrations is not yet completed.

This also can be observed in Figure 11 as shown by the blue colour (B). The complete mixing is achieved after the arc length of outlet slit greater than 1500 microns. This complete mixing represented by the green color of concentration in Figure 11 and the concentration profile in Figure 9 that shows a straight line at a concentration of 0.5 mol m^{-3}. The length of outlet slit has to be sufficient enough to ensure the complete mixing is achieved. This micro mixer was designed with a sufficient outlet length of 4000 microns which is beyond of the requirement. It can be predicted that with the presence of microchannel corrugated in the mixing slot, the possible output would be much better where the complete mixing is achieved at the arc length less than 1500 micron.

4. CONCLUSION

The simulation gives visualisation of the velocity profile and concentration profile inside mixing element of the micro mixer that could be difficult to obtain via experimental work. The inlet pressure has no effect to the concentration profile and only a small effect on the velocity profile. However, this simulation result might be different as the corrugated microchannel is excluded, and complete structure (instead of half structure) of the mixing element is used in this work. With the presence of corrugated microchannel, the velocity profile would be changed together with the changes in Reynold number when the fluid passes through the corrugated shape. The three types of laminar regions consisting of stratified flow, vortex flow and engulfment flow would need to be considered. The effects of inlet pressure would be also significant towards the velocity and concentration profile. These preliminary study would give the general overview of the properties of mixing element which will contribute to further study which is the mixing performance of this type of micro mixer.

5. ACKNOWLEDGEMENT

We gratefully acknowledge the financial support provided by the Fundamental Research Grant Scheme (FRGS) grant PJKIMIA 6071255 and Fellowship scheme (SLAB) of Universiti Malaysia Perlis (UniMAP).

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