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 visualize 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 it 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 study later on in the mixing performance of this type of micro mixer.*

Keywords : velocity, concentration, pressure

1. INTRODUCTION

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 enhanced the mass transfer and heat transfer rates that offer better yield and selectivity than the conventional reactors[1]. Several researchers studied on the mixing behavior 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 considerable attention in pharmaceutical[9, 10] and liquid dispersion study[11] is the Standard Slit Interdigital Micro Mixer (SSIMM). Standard Slit Interdigital Micro Mixer is an assembly of three components, namely a LIGA device containing the mixing element which embedded in a two-piece housing. The LIGA devices is 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 built of two pieces, the top and bottom plate connected to inlet and outlets (see Figure 1 (c) and Figure 1 (e)). The design of 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 1 (d)).[12]

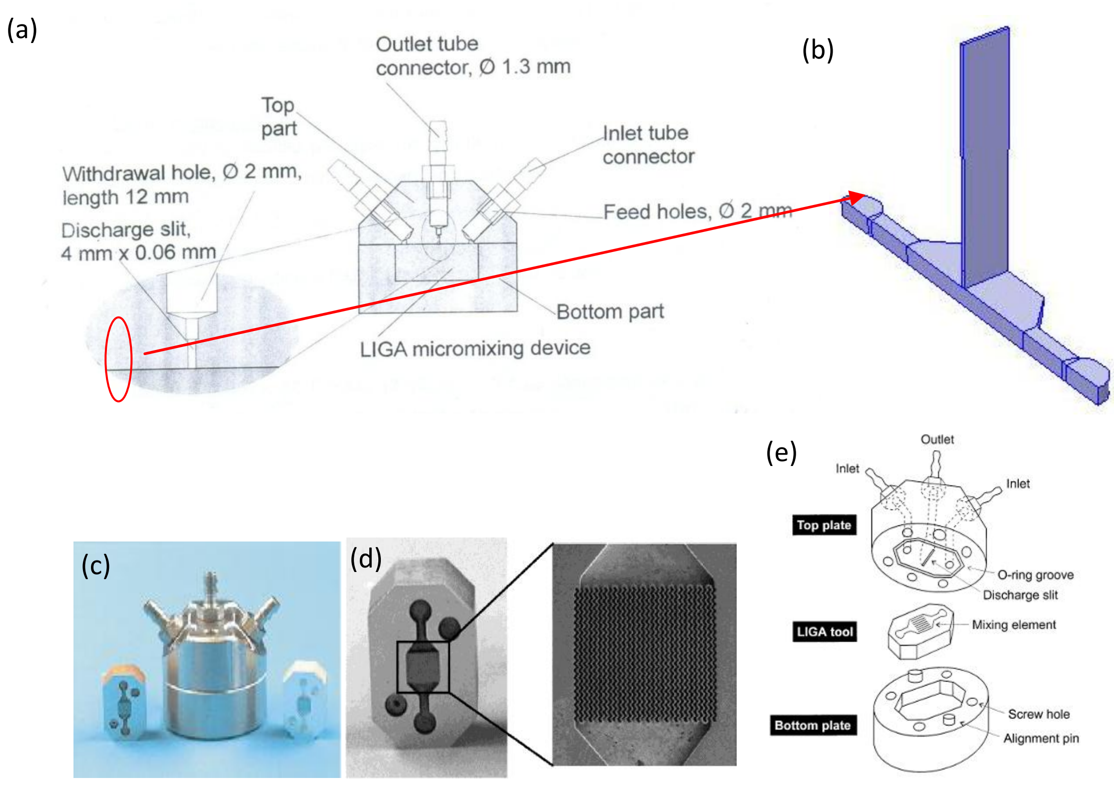

Figure 1: Standard Slit Interdigital Micro Mixer [12] (a) The schematic presentation of the assembly in the micro mixing system,-(Institut fur Mikrotechnik Mainz GmbH*)* (b) The model structure of SSIMM in COMSOL Multiphysics (c) The photograph of SSIMM (d) The mixing element (e) Explosion drawing of the SSIMM

The objective of this work is to visualize 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 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 1 (b) at different inlet pressure and the resulted velocity profile and concentration profile is observed.

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 1 (b) . 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 computational work was done by using numerical solution into solving the Navier Stokes Equation together with convection–diffusion equation.

2.1 Navier Stokes Equation

$$\rho \frac{\partial v}{\partial t} - \eta \Delta v + \rho(v \cdot \nabla)v + \nabla p = \mathbf{0} \qquad (1)$$

$$\nabla \cdot \mathbf{v} = 0$$

Where **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 pressures 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 equations is the convection–diffusion equations with a reaction term:

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

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 visualization 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 Figure 2 and Figure 3 below.

3.1 Velocity profile

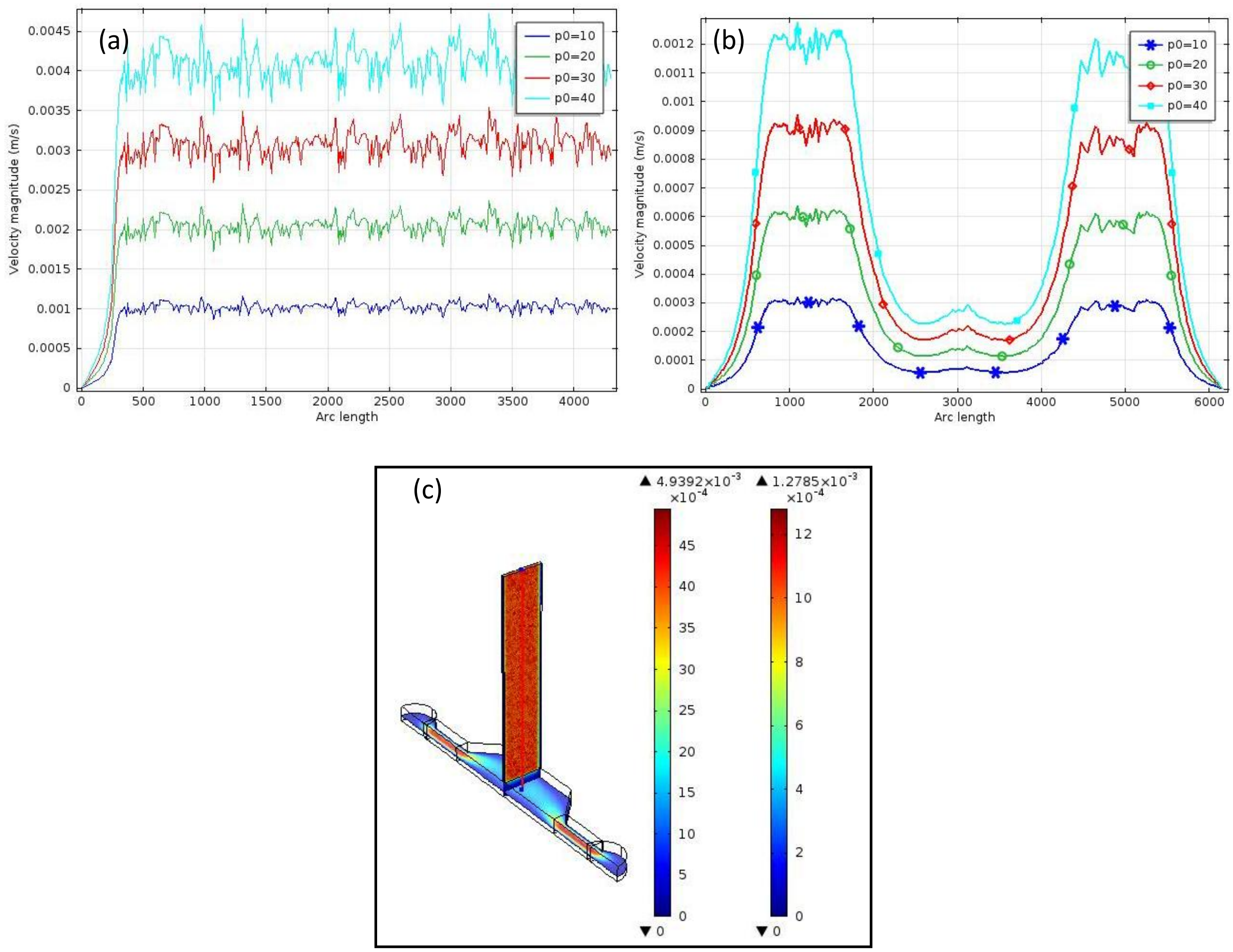

Figure 2 : The velocity profile of SSIMM from inlet 1 and inlet 2 to outlet; (a) Velocity profile along the outlet slit (b) Velocity profile in mixing element (c) velocity gradient of overall mixer

The velocity profile along the outlet slit and mixing element without microchannel for different inlet pressure can be seen in Figure 2 (a), (b) and (c). The outlet slit has higher velocity for higher inlet pressure as in Figure 2 (a). It can be seen that as the inlet pressure is increased from of 10 Pascal to 40 Pascal the velocity increases of velocity from 0.001 m/s to 0.004 m/s.

Also the variation of the velocity along the line is higher for higher inlet pressure which can be seen in Figure 2 (a). As compared to velocity profile within the mixing element in Figure 2 (b), 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 2 (c), the red color area represents the higher velocity or peaks as shown in Figure 2 (b) while the blue color represents the lower velocity. The change of inlet pressure gives a higher magnitude of velocity but the same pattern of the velocity profile. This visualization 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

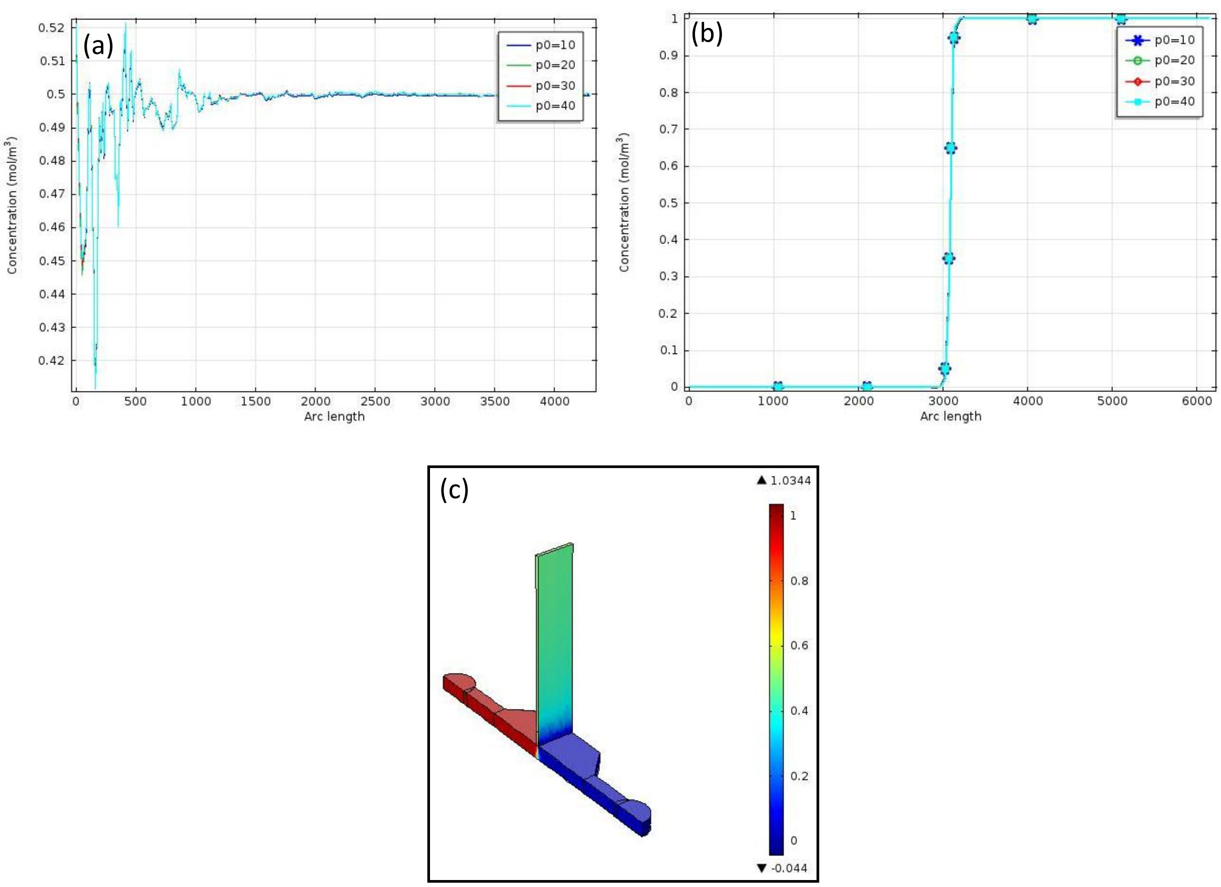

Figure 3: The concentration profile from inlet 1 and inlet 2 to outlet; (a) Concentration profile along the outlet slit (b) Concentration profile in mixing element (c) concentration gradient of overall mixer

The concentration profile along the outlet slit and mixing area for difference inlet pressure can be seen in Figure 3 (a), (b) and (c). The changes of inlet pressure do not have significant effects toward the concentration profile as the line overlaps with each other as in Figure 3 (a) and (b). 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 3 (a). In this region, the mixing of the two concentrations is not yet completed. This also can be observed in Figure 3 (c) as shown by the blue color . 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 3 (c) and the concentration profile in Figure 3 (a) 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 visualization 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 effects to the concentration profile and only small effect of the velocity profile. However this simulation result might be different as the corrugated microchannel is excluded and complete structure instead of half structure the of the mixing element used in this work. With the present 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 laminar region that consists of stratified flow, vortex flow and engulfment flow would need to be considered. The effects of inlet pressure would be also significant toward 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.

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