Passive T-Micromixer with Barriers for Laminar Flow

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Abstract - **Mixing in the passive micromixers depends on their geometry. Thus many passive micromixers are effective only at high Reynolds numbers and require a complex structure of channels. The article presents the possibility of improving the structure of T-micromixer for mixing two fluids with barriers. In our investigation we change 3 parameters: barrier height, barrier offset from the centre of the channel and barrier shape. The model shows high efficiency of mixing even at low Reynolds numbers Re = 0.1. Modified T-micromixer can be easily integrated into various labs-on-chip (LOC) or micro-total-analysis systems (µTAS).**

Keywords - **Microfluidic, lab-on-chip (LOC), micro-total-analysis systems (µTAS), Reynolds number, mixing, T-shape micromixer, laminar flow.**

I. INTRODUCTION

Microfluidic devices include many operations, such as sample pre-treatment and sample preparation, mixing, pumping, analysis, DNA sequencing, cell separation and detection [1]. Mixing is one of the most important part in the realization of labs-on-chip (LOC) or micro-total-analysis systems (µTAS) because microfluidic handling and operations carried out in these chips require rapid mixing of reagents and samples. Rapid mixing of two or more components or analytes is important for many microfluidic systems used in biochemical analysis or DNA analysis or microreactors with complex chemical synthesis. Mixing in the microscale is very difficult process, because it occurs by diffusion, which is very slow in microscale (mass diffusion coefficient D ~ 10^{-10} m^2/s). In most microfluidic devices the flow is laminar with very low Reynolds number and diffusion dominates the mixing process. For flow in a microchannel, the Reynolds number is generally defined as [2]:

$$\mathrm{Re} = \frac{v D_h}{\nu}, \tag{1}$$

where D_h is the hydraulic diameter of the microchannel(m), V is the mean velocity of the object relative to the fluid (m/s), ν is the kinematic viscosity (m^2/s). Laminar flow occurs at low Reynolds numbers where viscosity forces predominate inertial forces, and it is characterized by constancy of the fluid velocity distribution. Turbulent regime occurs at high Reynolds numbers when predominate the inertial forces, which is usually caused by chaotic swirl and other flow instability. Complete and full mixing of fluids at low Reynolds number takes a very long time and requires big length of the microchannel. For example, T-shape micromixer requires mixing length ~ 10 of cm. This makes it very inpractial for using in microfluidic LOC or µTAS systems. As in the micromixer is applied no external forces and mixing occurs only by diffusion, the only solution is to change the geometry of the channels so that the mixing was faster at shorter distances.

II. MICROMIXER DESIGN

The T-micromixer design and simulation were made in Comsol Multiphysics. The structure of micromixer is shown in Figure 1.

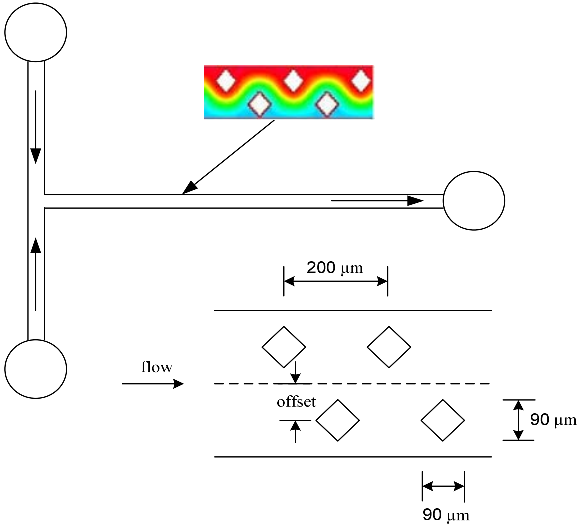


Fig.1 Structure and dimensions of T-micromixer with square barriers rotated for 45°.

The main idea of this study is to optimize and improve mixing parameters by changing the geometry of partitions and their placement [3]. In our investigation we change 3 parameters: barrier height, barrier offset from the centre of the channel and barrier shape. The square-shaped barriers were 90 x 90 µm (W x L), 200 µm between the centers and placed in the microchannel 200 µm wide and 50 high. Barrier has 3 different forms: square-, triangular- and circular-shaped. All dimensions are given in Table 1.

Modeled microchannel is 5 mm long. Simulation was done for steady incompressible flow, two fluids have physical properties of water with concentration of fluid species – first 0 and the other 1, diffusion coefficient D ~ 10^{-10} m^2/s. The velocity V ~ 0.1-1000 mm/s. Mixing stops when molar intensity is reached equal to 0.5 for both fluids. We turned the squares by degrees to prevent the formation of dead volumes in the microchannel.

TABLE 1

DIMENSIONS AND PARAMETERS OF THE T-MICROMIXER WITH BARRIERS

Microchannel	**Dimensions**	
	Width	200 μm
	Height	50 μm
	Length	5 mm
Barriers	**Dimensions**	
	Width	90 μm
	Height	0-50 μm
	Length	90 μm
	Offset	0-50 μm
	Spacing	200 μm
Barriers	**Form**	
	Square	◆
	Triangle	◀
	Circle	●

III. RESULTS AND DISCUSSION

All simulation were carried out at low Reynolds numbers Re = 0.1. Simulation result for different heights of barriers is shown on Figure 2. It shows that the best mixing – 48% was achieved when the barrier has a height of the channel (50 μm). Without barriers mixing efficiency of T-shape micromixer is only 22%.

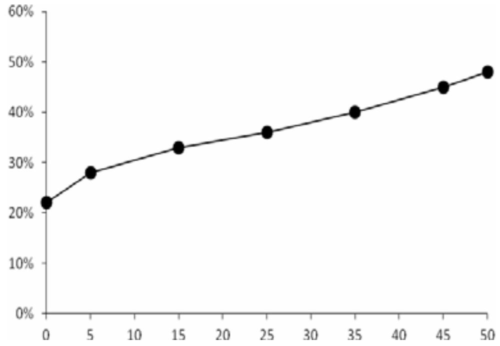


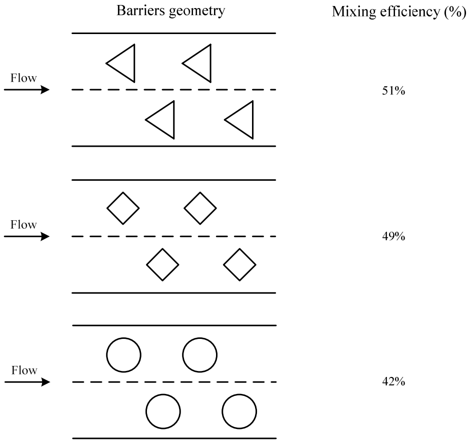
Fig.2 Mixing percentage for different heights of barriers.

To investigate the influence of the form of barrier, the study was carried out for 3 types of geometry: round, triangular, square (results presented in Table 2). Each form of barrier has the same dimensions 90 x 90 μm and 50 μm offset from the center of the channel. As the result, circular barriers showed the worst mixing (42%) and triangular barriers show the best mixing (51%), better than squares rotated for 45^{o} (49%), but triangular barriers have dead volumes and they are undesirable for further investigation.

At last, we investigated the displacement of the barrier from the center to the walls for a fixed barrier height of 50 micrometers and study that 20 μm offset gives 62% mixing for 5mm and 40 μm offset gives only 39% for 5mm, but the first offset gives only ~73% mixing for 10mm and the second gives ~79% mixing for 10mm. The results are shown in Figure 3.

TABLE 2

MIXING EFFICIENCY FOR 3 TYPES OF BARRIERS GEOMETRY.



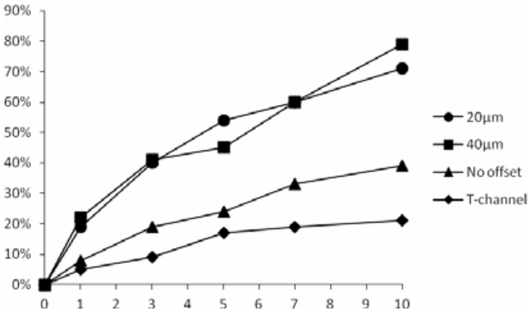


Fig.3 Results for different offsets.

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IV. CONCLUSION

In this article modified T-micromixer was presented. Geometry of passive T-micromixer was modified by integration in the structure of the microchannel barriers of different heights, shifted for a different value from the center of the channel and different shapes. Experimentally it was found that the optimum parameters of mixing are when the height of barriers is equal to the height of microchannel (50 μm), with offset from the center for 20-40 μm and with square shape of barriers rotated at 45 degrees. The modified T-micromixer provides effective mixing at low Reynolds numbers and it is very easy to realize and integrate into a complex microdevice.

ACKNOWLEDGEMENT

This work is supported by the FP7-PEOPLE-2010-IRSES project entitled “Developing Multidomain MEMS Models for Educational Purposes” (EduMEMS) number: 269295, funded from EU sources.