Micro mixture: Size effect of micro mixing

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ABSTRACT.

Micro fluidic devices have become commercially appealing due to their numerous applications in biotechnology and process engineering. Mixing rate is characterized by the diffusion flux given by the Fick's law. A passive mixing strategy is proposed to enhance mixing of two fluids through vortex. A numerical study of vortex passive mixers has been presented, which serves as an important alternative for developing technical solutions for improving the performances of micro mixers as well as size effect in mixture efficiency The numerical results indicate that the mixing performance can be as high as 92% within a typical mixing chamber of 0.5 mm diameter and 50 µm length when the Reynolds number is Re = 490. In addition, the results confirm that self-rotation in the circular mixer significantly enhances the mixing performance. The novel micro mixing method presented in this study provides a simple solution to mixing problems in micro system.

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Keywords*:* modeling, micro mixture, diffusion, size effect.

1 INTRODUCTION

As biochemical reactions that are performed in bio-MEMS require mixing, mixing is an important issue in bio-MEMS. There has been increasing interest among both biologists and researchers at the medicinal laboratories on the study of mixtures on a metric and micro scale. In the context of the MEMS, a numerical study on static micro mixers and the possible prospects for technical adapted solution of microsystems have been presented. Micro mixers can be classified under two categories, passive and active. Whereas external perturbations are introduced in active micro mixers to enhance mixing, the mixing process in passive mixers completely relies on diffusion or chaotic advection. Decreasing the diffusion path between the mixing fluids and increasing the contact surface between them will enhance mixing. The behavioral study of the micro flow mixers can enable the prediction of the state of the mixture and the efficiency of mixing.

A fast micro mixing is essential in many operations that are employed in biochemical analysis, administration of drugs, and also other biological processes involving handling of cells and enzymatic reactions, which occur in pharmaceutical products. When transverse-sectional dimensions of channel are approximately ten micrometers, the molecular diffusion can facilitate mixing of two fluids in few seconds. However, when dimensions are approximately hundred micrometers, a micro-mixer-based molecular diffusion can facilitate mixing in ten seconds [1]. The mixing is particularly ineffective in solutions containing the macromolecules, which have diffusion coefficients approximately one or two, very low compared to majority of the fluids [2, 11]. An effective mixing on a micrometric scale requires that the fluids be handled far away from surfaces, initially between distinct areas from the fluids so that the diffusion of fluids can supplement micro mixing over a reasonable period of time. However, the fast micro mixing produced by turbulent flows is not usually available at this scale of Reynolds number, which is typically below the threshold values evaluated for the turbulence transition. The literature describes significant number devices that have been designed to improve the mixing on a nanometric scale [3, 4, 5, 6]; these devices are the micro mixers that have been categorized into active and passive based on the pattern of control flow [7, 8, 9, 10]. The active mixers can produce an excellent mixture; however, they are often difficult to manufacture, operate, clean and are integrated in microsystems.

1.1 Modeling and simulation

The fundamental activity motivation is directly related to the design in microelectronics, micro system, or more generally in system. It is a making question; although it is possible to facilitate a downward step by a predictive modeling, it is finally based on the use of the multifield simulators [12]. Modeling of the technological processes on a micrometric scale is necessary to the comprehensive physical mechanisms that intervene with the various stages of the development of devices. The reduction of dimensions and the use of different technologies impose an increasingly definite knowledge of the physical mechanisms that contribute to the performances and heterogeneous assemblies of the components. Numerical simulation of the micro fluidic dynamics is employed to predict the self-rotation phenomenon [13], and to estimate the mixing performance under various geometric scales.

1.2. Species Transport Equations

When you choose to solve conservation equations for chemical species, FLUENT predicts the local mass fraction of each species, Yi, through the solution of a convection-diffusion equation for the ith species. This conservation equation takes the following general form:

$$\frac{\partial(\rho Yi)}{\partial t} + \nabla.(\rho \vec{v}\, Yi) = -\nabla.\vec{J}\, i + Si \qquad (1)$$

In the first equation, Ji is the diffusion flux of species i, which arises due to concentration gradients. By default, FLUENT uses the dilute approximation, under which the diffusion flux can be written as

$$\vec{Ji} = -\rho D_{i,m} \nabla Y_i \qquad (2)$$

Where $Di_{;m}$ is the diffusion coefficient for species i in the mixture.

1.3. Estimation of the efficiency of mixing

For estimating the mixing of index mixture, the following expression [16] is specified:

$$Ie = 1 - \frac{1}{\bar{M}} \sqrt{\frac{\sum (M_i - \bar{M})^2}{N}} \qquad (3)$$

$$\bar{M} = \sum \frac{M_i}{N} \qquad (4)$$

M_i , *and* $\bar{M}$ represent mass fraction of i pixel and average, respectively

2 NUMERICAL SIMULATION

A numerical simulation of mixing using the micro static mixers of vortex geometries by means of FLUENT 6.1 has been presented. The flow is assumed to be laminar and three-dimensional and permanent. The flow field of a micro mixer is governed by the incompressible Navier–Stokes equations. In this calculation, the values of µ and *D* are 998 kg/m^3, 0.001003 kg/m.s and 10^{-7} m^2/s, respectively.

In this study, the Reynolds number is defined as $\mathrm{Re} = \frac{V.Dh}{\nu}$ where *Dh* is the hydraulic diameter of the inlet micro channels *and V is* the velocity inlet, and ν The cinematic viscosity.

2.1 Geometry and boundary conditions

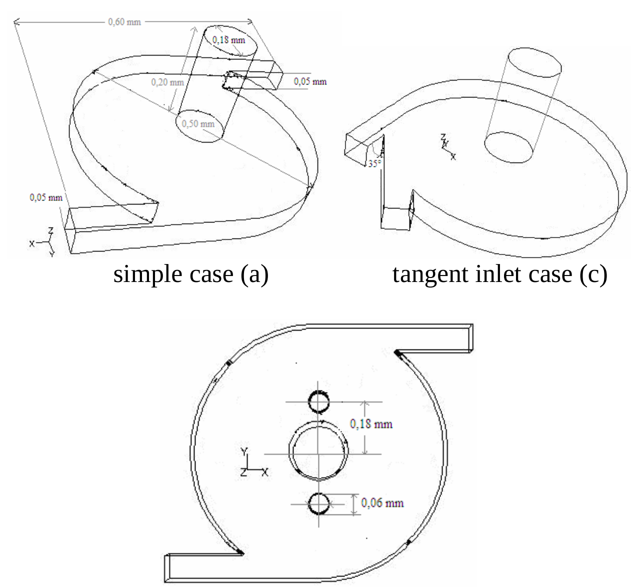
In the present simulations, the inlet pressure of two inlets is set in the range 100000 Pa. The fully developed condition is applied to the outlet micro channel. Meanwhile, the boundary condition of the micro chamber wall is specified as a no-slip condition with a zero flux of the sample concentration. This study effectuated discretization under the design criteria Pressure: standards, Pressure speed: Coupling: Simplec, Momentum: Second order,

Micrometric simple case (a)	Micrometric obstacles case (b)	Micrometric tangent inlet case (c)
79810 cells	81674 cells	86595 cells

Table 1. Meshing geometries of vortex mixer

2.1.1 Micrometric case geometry

Figure 1 presents the geometrical characteristics of the microfluidic mixers defined in this work.



simple case (a) tangent inlet case (c)

Obstacles case (b)

Figure. 1: vortex mixer geometrical characteristics

202

2.2. Numerical results

The mass fraction of mixture in the micro vortex of three configurations is described below

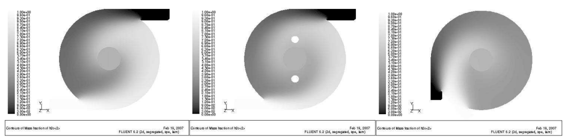


Figure. 2: Results of numerical simulation for the distributions of species concentration

Figure 2 shows the results of numerical simulation for the distributions of species concentration at different geometric micrometric cases. The self-rotation phenomenon induced in first and second micrometric cases enhances the performance mixing. In micrometric case (b), the presence of obstacles generates double rotation and enhances the performance of mixing. Figure 3 shows the results of numerical simulation for the distributions of species concentration at different cross-sections in the circular exit for micrometric simple case (a), when *Re* = 497.

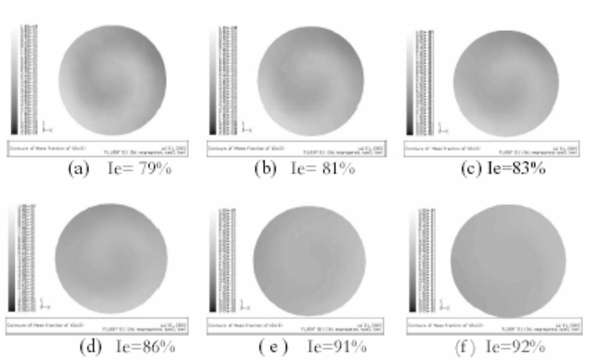


Figure 3. Results of numerical simulation for the distributions of species concentration at different cross-sections in the circular micro chamber at *Re* = 497: (*a*) *Z* = 60 µm, (*b*) *Z* = 70 µm, (*c*) *Z* = 80 µm, *(d) Z* = 100 µm, (*e*) *Z* = 150 µm and *(f) Z* = 200 µm.

Geometries	Simple case (a)	Case with obstacles (b)	Case tangent inlet (c)
Ie at 200 µm	92%	95%	95%

Table n°2 simulate micro mixture efficiency

The mixing efficiency of index mixture will be shown in table 2 for three micrometric cases at exit cross-section, and we represent the specie mass fraction of simple case in figure 4

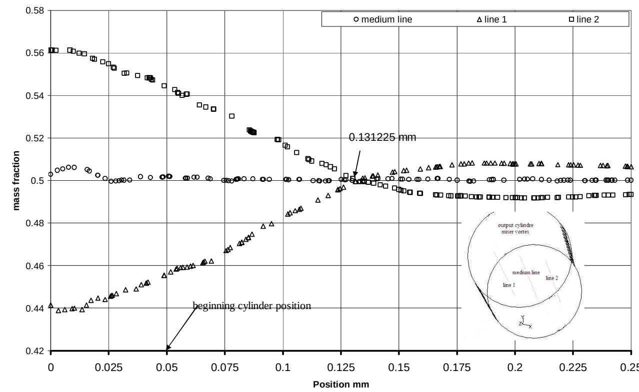


Figure 4 Distribution of species concentration of micrometric mixer simple case (a)

2.3. Simulation of milimetric case

These cases, simulation of milimetric case based on micrometric case augmented by 10 and 100 factors. The Reynolds number with identical boundary conditions compared with the micrometric case equals 49 and 4.9, respectively, for first and second milimetric cases.

The results for the distributions of species concentration at exit circular cross-sections, when *Re* = 497 and 49 and 4.9, respectively, for micrometric case and milimetric case X 10 and milimetric case X 100. As discussed above, a three-dimensional vortex is not induced in the circular exit chamber at this particular value of the Reynolds number. Therefore, at low Reynolds numbers, species mixing is dominated by the diffusion of the two last samples, millimetric cases X 10 (Re=49) and X 100 (Re=4.9)

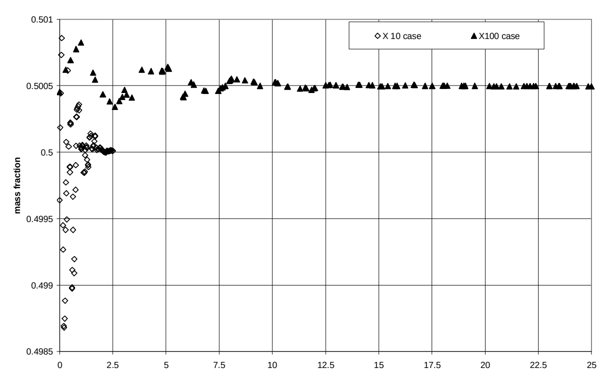


Figure 5 Distribution of species concentration of milimetric case (X10 and X 100) simple mixer case (a)

Figure 5 represent the, the mass fraction at medium line of output cylinder of milimetric cases

3 CONCLUSION

The results of the present numerical simulation provide a very clear understanding of the physical phenomena that take place in the three-dimensional vortex micro mixer. The numerical results have indicated that when the Reynolds number is equal to 490, a self-rotation effect is induced in the exit circular micro chamber, which generates a three-dimensional vortex. The results presented in this study provide a valuable reference for the further experimental development of integrated passive micro mixer with enhanced performance.

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