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ACTIVE SHEAR SUPERPOSITON MICROMIXER

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Summary We present a theoretical and experimental study of the mixing in a Micro Electro Mechanical System (MEMS). The mixer is an active micromixer. Its design consists of a main mixing channel where the main flow is perturbed by jet flows emanating from a series of secondary channels. The lateral flows oscillate in time and reorient the lamination of passive tracers from streamwise to cross-stream. The micromixer is a silicon-etched device where the main channel is 2h wide, 13h long and h deep (h = 100 microns). The secondary channels are 5h long and h/2 wide. The parameters (flow rate, frequency, and amplitude of oscillation) are accurately controlled. The mixing process is studied numerically and experimentally using flow visualizations techniques. The numerical simulations are performed for the 3-D flow. We present some flow properties using the Mixing Variance Coefficient (MVC).

Introduction

Mixing time of two fluids can be enhanced when the interface area between the fluids is increased by stretching and folding, so that diffusion between the fluids has to occur over a relatively small distance. At the microscale, the Reynolds number Re = UL/ν, where U is the characteristic velocity, L the characteristic lengthscale and ν the kinematic viscosity, is close to unity or smaller. The flow cannot be turbulent. A solution to enhance the mixing is to create a chaotic advection (Aref 1984, Ottino 1989) based strategy which has the advantage of producing an exponential rate of mixing, as opposed to an algebraic rate (e.g. t^{-1}), which is achieved e.g. by inducing vertical motion. Thus advective stretching and folding is still desirable in order to improve the effective diffusion coefficient.

The microscale mixers can be divided in two broad classifications: the active and the passive micromixers. If there are no moving parts used to produce the mixing, the mixer is defined as passive micromixer (Miyake et al. 1993, Stroock et al. 2002, Song et al. 2003). These passive designs are such that the flow in the channel is fully three-dimensional, which is a necessary condition for a laminar steady flow to have chaotic trajectories. The first active micromixer developed by (Evans et al. 1997) is based on chaotic advection resulting from a source/sink system, where unmixed fluids are pumped into a mixing chamber, and then two source/sink systems are alternately pulsing the flow.

The current design of the micromixer studied here, called “shear superposition micromixer”, was developed at UCSB in 1998 (Volpert et al. 1999). This is a continuous through-flow micromixer consisting of a main channel with three cross-flow side channels that are capable of producing time-dependent shear flow in the direction transverse to the main stream (see figure 1). A micromixer design with one transversal secondary channel has been presented recently in Lee et al. 2001. A configuration with multiple side channels is mathematically investigated in Niu and Lee 2003.

The choices of frequencies and phase shifts for optimal mixing previously discussed in Volpert et al. 1999 are not obvious and are the subject of current investigations for the three-dimensional configuration. We evaluate the mixing using the mixing variance coefficient function (MVC) (Mathew et al. 2003) both in the experiments and in the numerical simulation. We present a study where the velocity in the side channel is large compare to the main flow.

Micromixer Design and Experimental Methods

The micromixer design is shown in Figure 1. Flow in the main channel is manipulated by controlling time-dependent oscillating flow from three pairs of secondary channels. The secondary channels induce time-dependent cross-stream momentum on the main channel flow which affects the fluid motion. A top view picture of the experimental chip is shown in Figure 1a and a description of the fluid motion in the mixer is shown in Figure 1b. The effectiveness of the mixer is evaluated using several different flow configurations by varying the frequencies and the amplitude of oscillation within the secondary channels.

A 3-D Poiseuille profile is specified at the entrance of the main channel, which is eventually perturbed by the secondary channels. The pressure at the entrances of the secondary channels, far from the main channel, is specified to be sinusoidal in time, with each pair having independent frequencies. The numerical simulations are performed with the mmercial CFD software FLUENT.

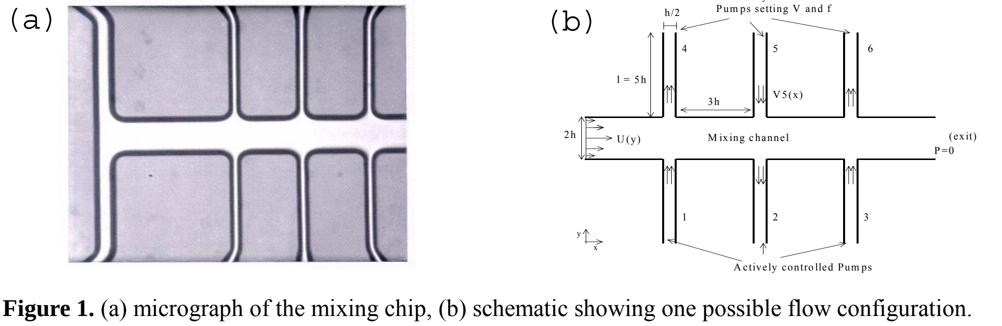

Figure 1. (a) micrograph of the mixing chip, (b) schematic showing one possible flow configuration.

RESULTS

Modeling

The velocity in the plane (x,y, z = *h*/2) for the main channel is measured by PIV (Particle Image Velocimetry) and is compared with the analytical solution and the numerical simulations. By solving the Navier-Stokes equation using the Fourier series expansion, we fund the solution of the time-dependent flow in the side channels which has been validated by the PIV measurements. The flow behavior at the junction of the main channel and the side channel is experimentally studied in details (figure 2(a,b)). We propose a simple model for the flow in the micromixer which is the superimposing of both analytical solutions. This model provides an estimation of the mixing based on the residence time of the fluid particle.

Mixing Variance Coefficient measurements

We are interested in the distribution of the fluid particles in the micromixer mainly at the exit of the channel. We used the so-called mixing variance coefficient (MVC) function to quantify a homogenous particles distribution of the two fluids initially unmixed at different scales. The MVC is defined as follows $MVC = \frac{1}{S^2}\sum_{1}^{S^2}(\rho_k - 0.5)^2$ where S^2 is the total number of boxes and ρ_k is the average particle label in the box *k*. S defines the size at which we look at the mixing. The best mixing is achieved when the mixing variance coefficient is equal to zero. The MVC definition can be extended to the experimental measurements. In this case, the mixing is analyzed by taking pictures of the channel through a microscope. At the entrance of the main channel, the water appears dark and the dye white.

We analyze the flow behavior at the intersection of the main channel and the side channels for different amplitudes and frequencies. At large amplitude and frequency the flow visualization and the PIVmeasurements show two recirculation regions (figure2) on each side of the side channel axis. These recirculation regions are not symmetric due to the main flow and depend on the velocity in the side channel

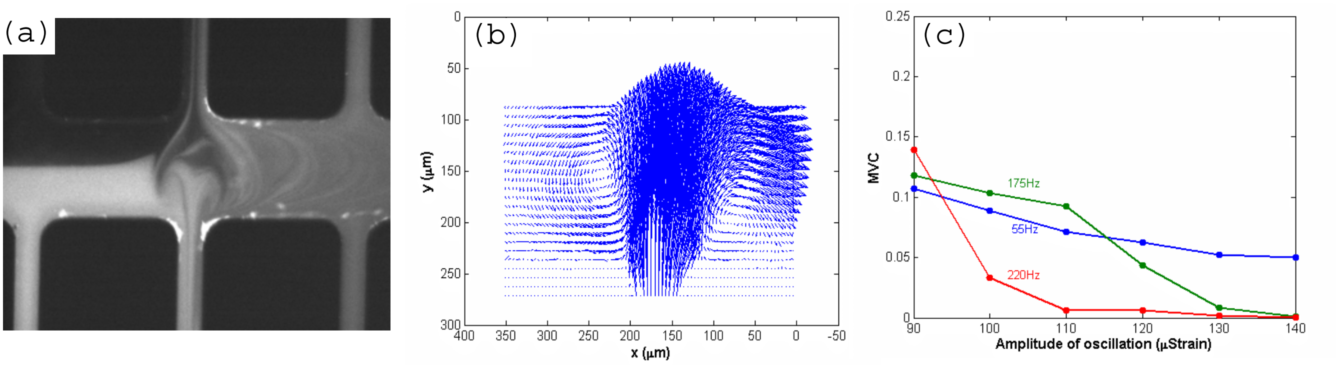

Figure2: (a) flow visualization for large amplitude of oscillation and large frequency in the middle plane. (b) PIVmeasurement in the same configuration. (c) MVC for different frequencies and amplitudes.

Figure 2c shows the MVC for different amplitudes of oscillation and different frequencies when one pair of side channels is activated. The re-circulations improve the mixing by adding some stretching and folding in the main flow.

CONCLUSION

The results presented here correspond to an analysis of the mass transport in an active micromixer. An analytical solution for the steady flow in the main channel and for the unsteady flow in the side channel is compared successfully with the experimental measurements obtained by micro-PIV and a simple model is proposed. Flow visualizations and PIV measurements show two non-symmetric recirculation regions when the velocity in the side channels is larger than in the main channel. Measurements of the mixing using the MVC function for one pair of side channels activated show a mixing increasing with the amplitude and the frequency of the oscillations.