8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

Numerical Simulation of Tridimensional Micro-Mixing

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Key Words: Microfluidics, multifluid jets, 3D simulations, Level Set method

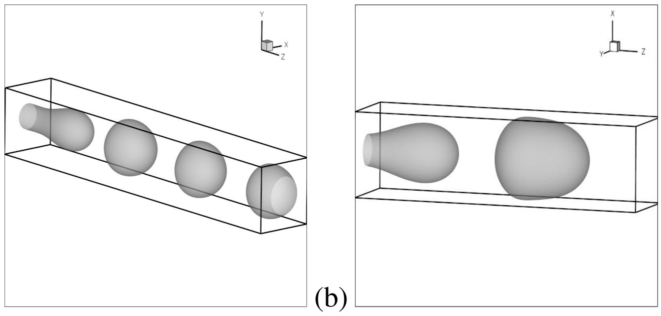
ABSTRACT

Microdroplets are often employed for their internal hydrodynamic to mix products that are generally toxic and expensive. In this paper, we propose the analysis of the formation of the biphasic jet, the breaking of the internal phase, the creation of the microdroplet and finally the study of the internal dynamic of the formed droplet. In order to have quantitatively correct results, we perform tridimensional simulations. Because of the size of the capillary edge used in microfluidics (about a hundred micrometres of section) and of the velocity of the flows (a few centimeters per second), the effect due to confinement and surface tension are predominant. Generally, the Reynolds number is smaller than one and effects due to the gravity are negligible.

We use the Stokes equations for diphasic flows with surface tension. The Level Set method proposed by Osher and Sethian (1988) is used to follow the evolution of the interface. To solve this system, we use a finite volumes scheme for the Stokes equation and a WENO5 scheme for the hyperbolic advection equation. The surface tension term is treated explicitly in the Stokes system. This introduces a CFL condition for the time step. We use the stability condition introduced by Galusinski and al (2007) for laminar flows with high confinement. Experimentally, the jet is generated with a cylindrical capillary centred in a square channel. Numerically, the same configuration is adopted. The external microchannel has a square section $S_c = (550\ \mu m)^2$ and the radius of the cylindrical tube is $R_i = 105\ \mu m$. The inner fluid has a viscosity of $\eta_i = 55mPa.s$ and the outer one $\eta_e = 235mPa.s$. The surface tension between the two fluids is $\gamma =\ 24mN/m$.

In a first configuration whose results are proposed on Figure 1 (a), the flow rate are respectively: $Q_e = 5500\mu L/h$ and $Q_i = 2500\mu L/h$.

At the formation of the droplet the jet is pinched and a filament connects the two sides of the jet. Then, it breaks and the surface tension smooths the shape of the resulting droplet that reaches its steady state.



(a) (b)

Figure 1: Formation of a jet and creation of three droplets when (a) $Q_e = 5500\mu L/h$ and $Q_i = 2500\mu L/h$ and (b) $Q_e = 3000\mu L/h$ and $Q_i = 2500\mu L/h$:

In a second configuration (Figure 1 (b)), the external flow rate is smaller. With this kind of parameters, the created microdroplets have bigger volumes and their shape is modified by the section of the microchannel.

In order to understand the internal dynamic of the droplets, it is interesting to plot the droplets velocity fields in theirs own referential.

One can observe the effect of the geometry on the droplets shape (Figure 2 right) and on the flow in itself that passes through the corner. We will present comparison of our results with experimental ones. Once these results are validated by experiments, one can use the velocity field inside the droplet in order to build a micro-mixer.

We consider the mixing by convection and diffusion of two species inside the droplets. This is done numerically by using a mixing model involving the velocity field computed above assuming that the viscosity inside the droplet does not depend on the composition of the mixing. We will present preliminary results on the efficiency of the mixing.

(a) (b)

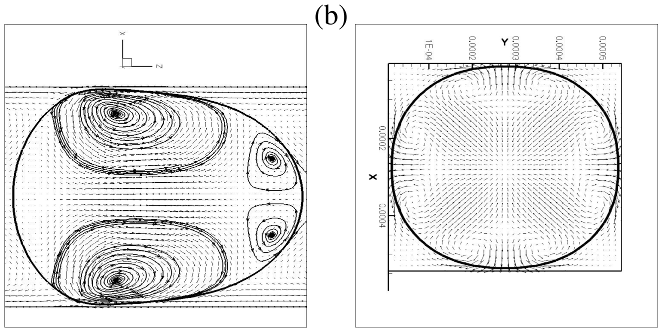


Figure 2: Example of the use of droplets as micro-mixers (shape of the droplets in different slices,velocity field and and few streamlines in droplet frame of reference): (left) Shape and velocity field in the (x,z) plane; (right) Case of the plug in the (x,y) plane.

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