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Numerical Analysis of the Micro-mixer Uses Hydrodynamic Instability

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Abstract: The micro mix is particularly interesting for many micro fluidic applications. In micrometric size of the devices, achieving an effective mixing is often difficult, due to the laminarization of the flow. Many solutions are proposed in the literature to overcome this issue. As an example, effective mixing can be achieved by using a secondary pulsed flow to destabilize the diffusion layer between the two fluids to be mixed. This layer is then stretched and folded which leads to an improved chaotic mixture. However, this technique requires specific actuation, making the micro system more complex and knives. Our idea is based on a mixer used hydrodynamic instability generated by a micro fluidic oscillator to destabilize the diffusion layer between the two fluids to be mixed, We add that the idea can be printed easily on a silicon plate and cheaper and The oscillators generally have a simple geometry and can be considered as a vibratory system at a frequency and an amplitude which is represented by an injected mass flow. In this work, we study an integrated mixer with a micro oscillator; several cases are studied numerically for liquid fluids using the CFD code. Practically, we want to follow numerically the variation of the efficiency of micro fluidic mixer in parallel with the change in the frequency of injection of the two phases has mixed.

Keywords: Micro fluidic, Hydrodynamic instability, Micro oscillator, Micro mixer

I. INTRODUCTION

The micro mix is particularly interesting for many micro fluidic applications. In micrometric size of the devices, achieving an effective mixing is often difficult, due to the laminarization of the flow. Many solutions are proposed in the literature to overcome this issue. As an example, effective mixing can be achieved by using a secondary pulsed flow to destabilize the diffusion layer between the two fluids to be mixed. This layer is then stretched and folded which leads to an improved chaotic mixture [1]. However, this technique requires specific actuation, making the micro system more complex and knives.

$$\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}\right)$$

II. NUMERICAL SIMULATION OF THE MICRO MIXER USES HYDRODYNAMIC INSTABILITY

Mathematical Formulation

A mathematical formulation must necessarily express the behaviour of this phenomenon in space and in time. In fluid mechanics, it is assumed that the fluid is a continuous medium [2-4], which makes it possible to use the classical laws of conservation, namely:

The Equation of Conservation of the momentum (1)
The Mass Conservation Equation (2)

Simplifying Assumptions

The flow is incompressible

The flow is stationary
The flow is of type 2D

$$\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}\right) \quad (1)$$

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}=0 \quad (2)$$

The integration of the formulations that govern the phenomenon of mixing.

When you choose to solve conservation equations for chemical species, FLUENT predicts mass fraction of each species, *Yi*, by the solution of a convection-diffusion equation for the i_{th} species. This conservation equation takes the following general form:

$$\frac{\partial(\rho Y_i)}{\partial t}+\nabla.\left(\rho\vec{v}Y_i\right)=-\nabla.\vec{J_i}+S_i \quad (3)$$

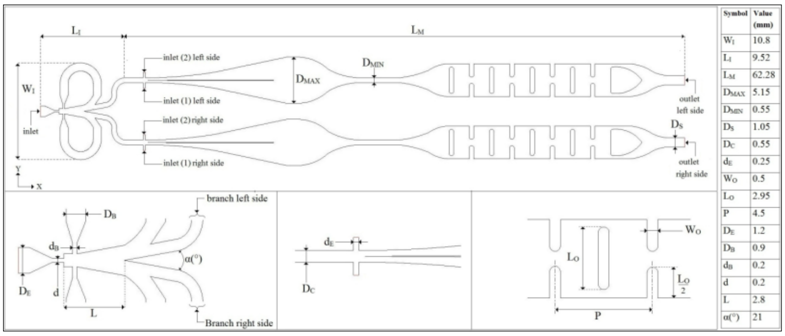
In the first equation, J_i is the diffusion flux of species *i*, which comes from the concentration gradients. By default, FLUENT uses the diluted approximation, under which the diffusion flux can be written as:

$$\vec{J_i}=-\rho D_{i,m}\nabla.Y_i \quad (4)$$

Where $D_{i,m}$ is the diffusion coefficient for species *i* in the mixture cm^2s^{-1}.

Geometry and Mesh

It is an integrated mixer with an oscillator which contains an inlet and two discharge branches and is 10.8 mm wide and 9.52 mm long, the mixer consists of two identical parts. Each part is connected to a discharge branch. Each part has two inputs so as to pass through the phase (2) in the mixer, in contrast, for the phase (1) witch it entering the oscillator first, and then periodically injected into the right and left sides of the mixer, mixer contains an integrated widening with narrowing [5,6], each part contains a series of obstacles placed face to face with the flow for mixing out of the mixer through two outlets (outlet of the left part, outlet of the right part) (Fig. 1).



Symbol	Value (mm)
W_I	10.8
L_I	9.52
L_M	62.28
D_{MAX}	5.15
D_{MIN}	0.55
D_S	1.05
D_C	0.55
d_E	0.25
W_O	0.5
L_O	2.95
P	4.5
D_E	1.2
D_B	0.9
d_B	0.2
d	0.2
L	2.8
$\alpha(°)$	21

Fig. 1. Description of the simulated fluid mixer geometry.

Boundary Conditions

Once we have represented the geometry of the system studied, for the first example we must set conditions at the limits of the system on the values of the input pressure P = 2.78 bar for the oscillator (pressure of the secondary inputs 1 and 2 of the right and left mixer part p = 1.6), the pressure of the two left and right outlets respectively set to 1 bar, the flow fluid is water with a normal dynamic viscosity equal to $\mu = 0.0008$ kg/ms, the mixture will be characterized by a mass fraction M, fixed equal to 100% at the input of the oscillator and 0% for the other inputs; an optimum mass fraction is thus sought in outputs of 50%.

III. RESULTS AND INTERPRETATION

Mass Flow Rate (Micro Oscillator)

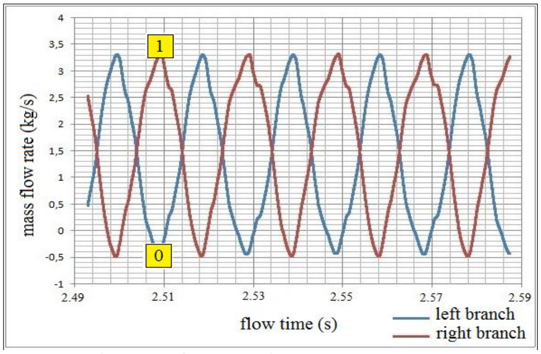


Fig. 2. The mass flow as a function of time (s) To branches (right and left).

We can notice the tilting of the fluid (the water) to the left and to the right, the evolution of the mass flows is regular, and quasi sinusoidal (Fig. 2).

Velocity Magnitude and Total Pressure (Micro Oscillator)

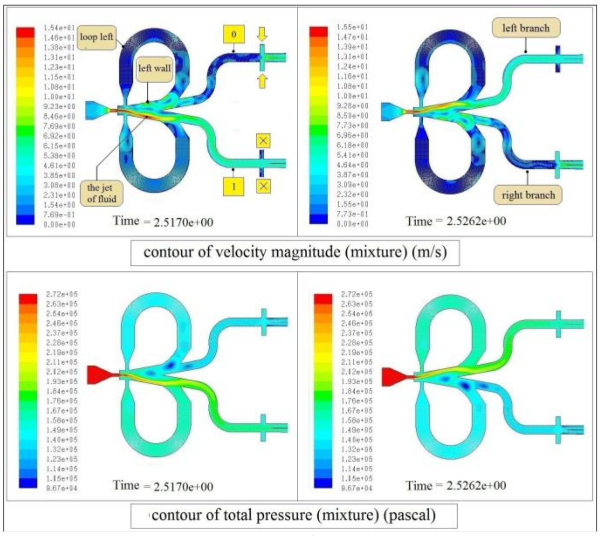


Fig. 3. Velocity magnitude and total pressure of the micro-oscillator at two distinct instants.

By analyzing (Fig. 3) we conclude that the micro oscillator is governed by a well-known phenomenon which is the Coanda effect. The jet of fluid flowing between two walls tends to attach to the one closest to its axis. The presence of two control loops makes it possible to cause the jet to oscillate. Indeed, the progressive increase of the pressure on the side of the attachment at the inlet of the loop and at the base of the jet causes the latter to tilt towards the opposite wall and the same phenomenon recurs. We also conclude that the periodic variation of the total pressure in the right and left branches makes the flow of liquid into the small inlets periodically.

Mass Fraction and Velocity Magnitude and Total Pressure (Micro-Mixer)

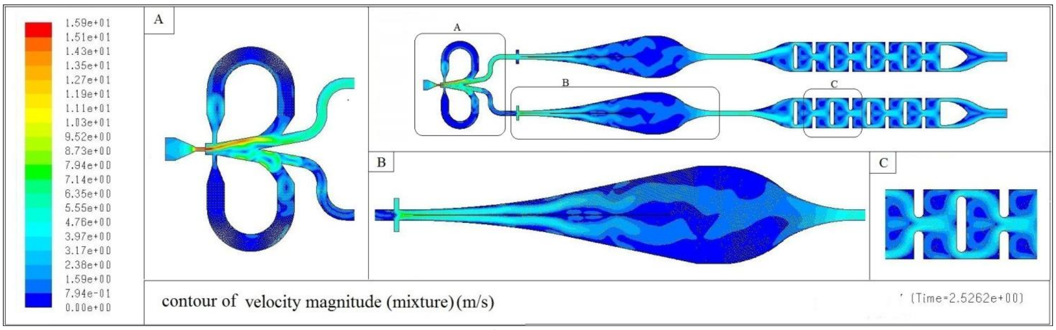


Fig. 4. Represents the contour of velocity magnitude in the micro-mixer.

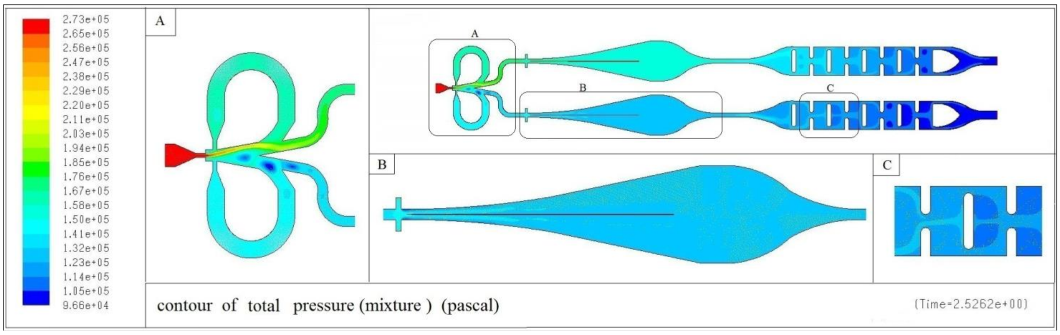


Fig. 5. Represents the contour of total pressure in the micro-mixer.

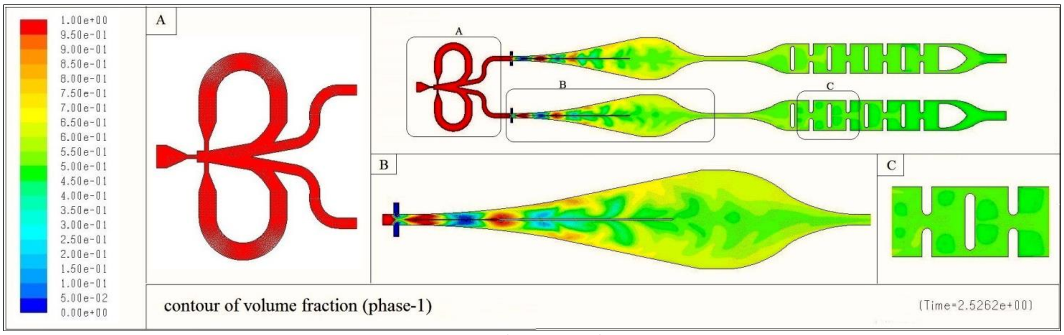
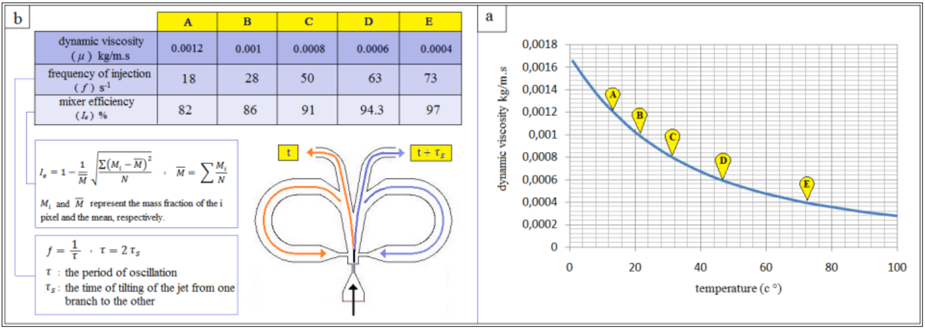


Fig. 6. Represents the contour of the mass fraction in the micro-mixer.

It will be noted (Figs. 4 and 5) a gradual decrease in velocity magnitude at the beginning of the widening due to the continuity of the fluid, because each times the diameter of the flow increases, the speed decreases. Enlargement makes it possible to slow down the average flow velocity to gain a little time to increase the mixing process. Enlargement also makes it possible to increase and destabilize the contact surface between phases (1) and (2). With respect to (Fig. 6), this proves what we have said before. The liquid of phase (1) enters the oscillator first and then periodically injected into the right and left sides of the mixer due to oscillation of fluid within the oscillator.

Study of the Influence of the Injection Frequency on the Efficiency of the Micro-fluidic Mixer Studied

According to a study mentioned in our scientific article, we found that the frequency of the oscillator increased with decreasing viscosity of the liquid. Consequently, different viscosity values (A, B, C, D, E) were chosen to give us different injection frequencies in order to know the effect of the latter on the mixing efficiency. the viscosity can change from one liquid to another, or by heating the liquid since the viscosity is sensitive to the temperature variation especially the case of water and there is a curve (Fig. 7a), influence of temperature on the dynamic viscosity of the water. The curve shows that the viscosity of the water decreases progressively due to the increase in temperature.



	A	B	C	D	E
dynamic viscosity (μ) kg/m.s	0.0012	0.001	0.0008	0.0006	0.0004
frequency of injection (f) s^{-1}	18	28	50	63	73
mixer efficiency (I_e) %	82	86	91	94.3	97

$$I_e = 1 - \frac{1}{\overline{M}}\sqrt{\frac{\Sigma(M_i - \overline{M})^2}{N}} \quad , \quad \overline{M} = \sum \frac{M_i}{N}$$

M_i and $\overline{M}$ represent the mass fraction of the i pixel and the mean, respectively.

$$f = \frac{1}{\tau} \quad , \quad \tau = 2\tau_s$$

τ : the period of oscillation

τ_s : the time of tilting of the jet from one branch to the other

Fig. 7. (a) The curve of the viscosity variation dynamics of water as a function of temperature; (b) The efficiency of the micro-mixer for different injection frequencies.

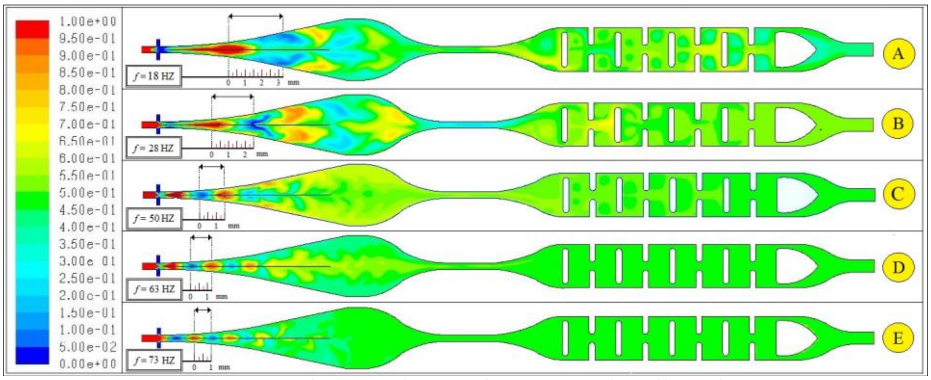


Fig. 8. Represents the contour of the mass fraction of micro-mixer for different frequency injections.

The first results of the numerical calculation indicate the evaluation of the frequency response (the fluid injection frequency), it increases with the decrease in the dynamic viscosity. We also note that the mixing efficiency increases with increasing frequency injection (Fig. 7b).

Note that in Fig. 8 the mixer efficiency varied in proportion to the increase in the frequency injection, in particular for cases A and B, the mixing process is carried out in two steps, the first stage being in the enlargement and second stage is done in vortices located behind the obstacles that placed face to face with the flow. On the contrary, for the cases D and E the first step is sufficient to maximize the efficiency of the mixer.

$$\tau_m = \frac{L^2}{D} \tag{5}$$

L : distance between two fluids to be mixed (m)

τ_m : the time required for mixing (s)

D : diffusion coefficient (cm^2s^{-1})

This is due to the reduction of the distance required for the diffusion of liquid from phase 1 into the liquid of phase 2 due to of the increased frequency of injection. Scottish chemist écossais Thomas Graham law shows that the smaller distance between Phase 1 and Phase 2, the less time is needed for mixing.

IV. CONCLUSION

This research is a contribution to mixing in microchannels. The study was carried out by a two-dimensional numerical simulation, using the fluent commercial software. We studied in the first phase the flow in a micro oscillator and the nomination of Notes in depth, and in the second phase we studied and explained the operating principle of our proposed mixer. The results of this simulation showed an instability of the diffusion layer between the two fluids to be mixed. We also add that with the study of the influence of the frequency injection on the efficiency of the microfluidic mixer studied, we conclude that the hydrodynamic instability has a clear influence on the efficiency of the mixture despite the regime of The flow is highly laminar.

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