Numerical Analysis of an Integrated Micro-Mixer with a Micro-Oscillator using a T-junction

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Abstract: Flows based on microfluidic oscillators are among the most studied flows in micro-system technology both because of their frequent occurrence in nature and their uses in many industrial applications. These flows have also been the subject of numerous academic studies because they generally have a simple geometry and can be considered as a vibratory system having a frequency and an amplitude which is represented by an injected mass flow. Most micro-mixers are often characterized by laminar flow and the effective mixing process is often difficult, 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. In this work, our proposed idea is based on the use of unsteady movements generated by a micro-oscillator to hydrodynamically destabilize the diffusion layer between the two fluids to mix in a micro-mixer; we add that the design of this idea can be easily printed on a cheap and portable Micro fluidic chip. By talking about the large proportion of our work, we study an integrated micro-mixer with a micro-oscillator using a T-junction; 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-mixer in parallel with the Change of the frequency of oscillator when injected the two fluids has mixed. This work has been developed at the level of the ENERGY laboratory in ARID Zones (ENERGARID).

Key words: micro fluidic, laminar flow, micro-oscillator, micro-mixer, T-junction.

Nomenclature

T	Temperature of the water liquid,	C °
f	Frequency of the oscillator , (HZ) or	s^{-1}
J_i	Diffusion fluxes of species i,	$kg.m^{-2}s^{-1}$
Ys	Inflexion point ,m	
v_x	Fluid velocity along the x-axis,	$m.s^{-1}$
v_y	Fluid velocity along the y-axis,	$m.s^{-1}$
p	Pressure, Pascal	

Greek Symbols

μ	Dynamic viscosity,	$Kg.m^{-1}.s^{-1}$
ν	kinematic viscosity,	$m^2.s^{-1}$
ρ	Mass density,	$kg.m^{-3}$

Notations

$\frac{\partial}{\partial t} or \frac{\partial}{\partial x} + or \frac{\partial}{\partial y}$ Partial dérivative

Non-dimensional Numbers

I_e	Mix efficiency index,	%

1. Introduction:

The field of application of oscillators is vast, in this introduction; a concise summary of the work done in this area was presented. The fluidic oscillators can also be used to make the micro mix [2] by using them in various configurations, which we will describe hereinafter. They can also improve heat transfer [3], act as actuators for active flow control [4] or propeller jet vectorization [5], and serve for surgical applications as oscillating scalpel actuator [6].

When we talk about innovative design in this paper, we connect a T-junction with each branch of the micro-oscillator to make the system a fluidic pump that utilizes the periodic change of the pressure in the T-junctions resulting from the oscillation of fluid in the oscillator for to absorb liquids from small inlets by making a negative difference pressure in the T-junction and pumping them into the micro-mixer enlargement by making a positive difference pressure in the T-junction, we have simulated at several cases to determine the effect of liquid viscosity on the frequency of periodic change of pressure in the T-junction in order to accelerate and improve the mixing process, in addition to our design of the obstacles and their location in the mixer in order to increase the diameter and the number of mixing vortex without loss of large kinetic energy in the liquid stream.

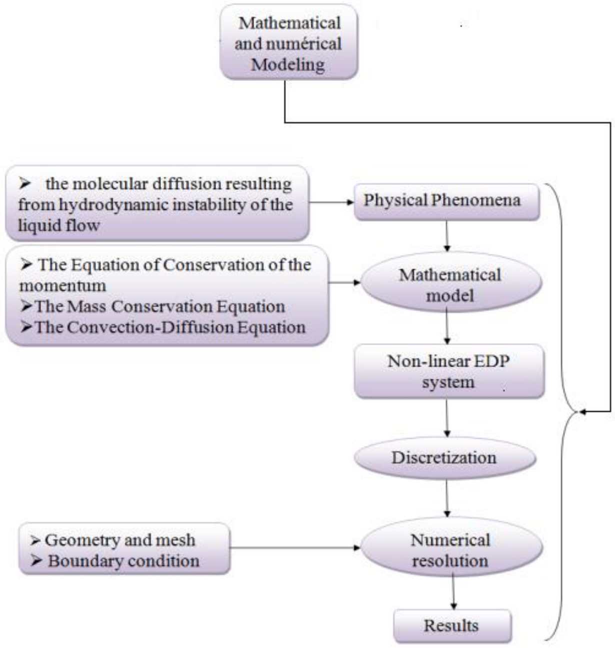


Fig.1. Logical flowchart of the mathematical and numerical modelling for our micro mixer.

2. Numerical Simulation of an Integrated Micro-Mixer with a Micro-Oscillator using a T-junction:

2.1 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, 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)

2.2 simplifying assumptions:

- The flow is incompressible
- The flow is in stationary
- The flow is of type 2D

$$\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}\right)\quad(1.1)$$

$$\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}\right)\quad(1.2)$$

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

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:

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

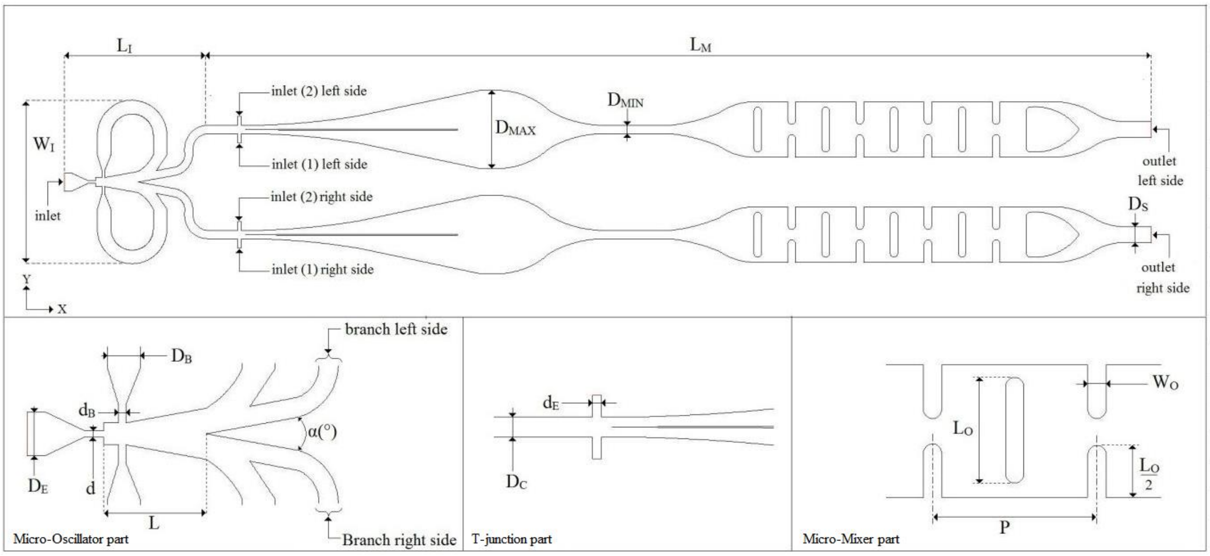
In the first equation, J_i is the diffusion flux of species i, which comes from the concentration gradients. By default, FLUENT uses the diluted approximation, under which the diffusion flux can be written as

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

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

2.3 Geometry and mesh:

It is an integrated micro-mixer with a micro-oscillator which contains an inlet and two branches and is 10.8 mm wide and 9.52 mm long, the micro-mixer consists of two identical parts. Each part is connected to a branch using a T-junction. Each T-junction has two inputs so as to pass through the phase (2) in a part of the micro-mixer, in contrast, for the phase (1) witch it entering the oscillator first, and then periodically injected into the right and left sides or parts of the micro-mixer, mixer contains an integrated widening with narrowing, each part of the micro-mixer contains a series of obstacles placed to collide with the flow , The mixture leaves the mixer through two outlets (outlet of the left part, outlet of the right part).



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
α(°)	21

Fig.2. Description of the simulated fluid mixer geometry.

2.4 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 μ = 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%.

3. Results and interpretation:

3.1 Mass flow rate (micro-oscillator):

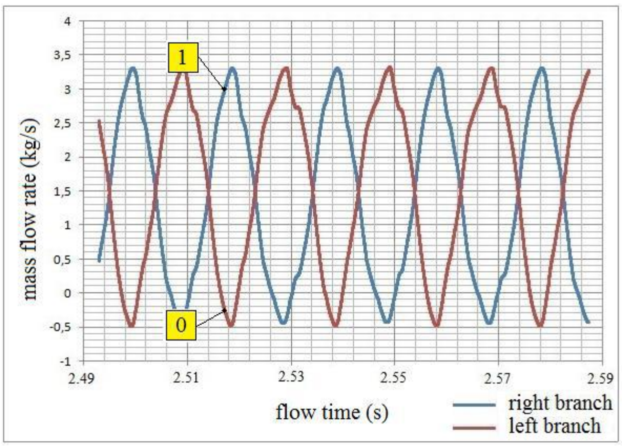


Fig.3. Mass flow as a function of time (s) to branches (right and left).

(**Fig. 3**) 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.

3.2 Velocity magnitude and Total pressure (micro-oscillator):

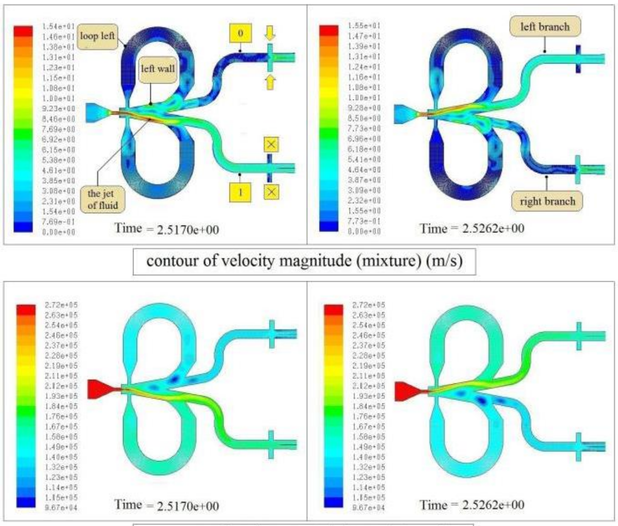


Fig. 4. Contour of velocity magnitude and total pressure of the micro-oscillator at two distinct instants.

By analyzing (**Fig4**) 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 of the T-junctions periodically.

3.3 Mass fraction and Velocity magnitude and Total pressure (micro-mixer):

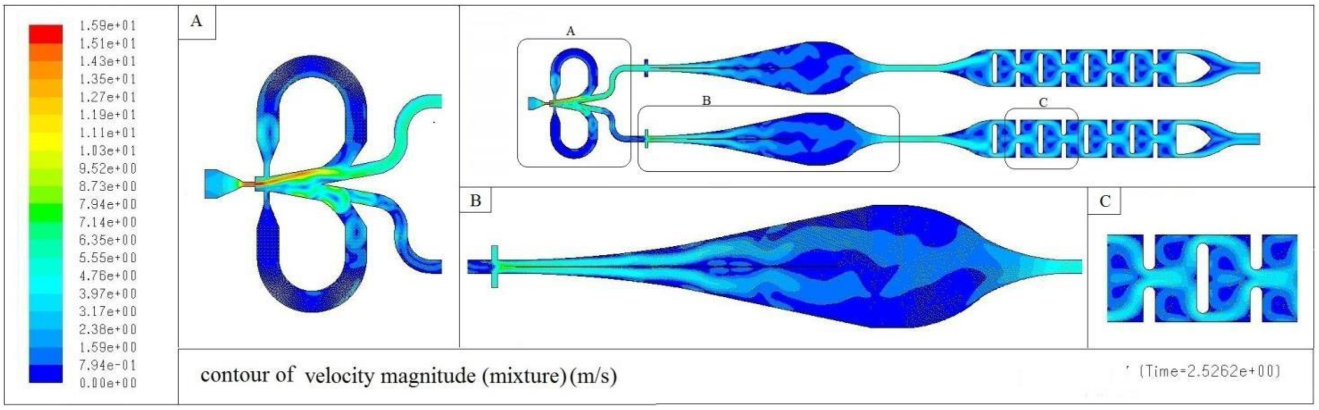


Fig.5. Contour of velocity magnitude in the micro-mixer.

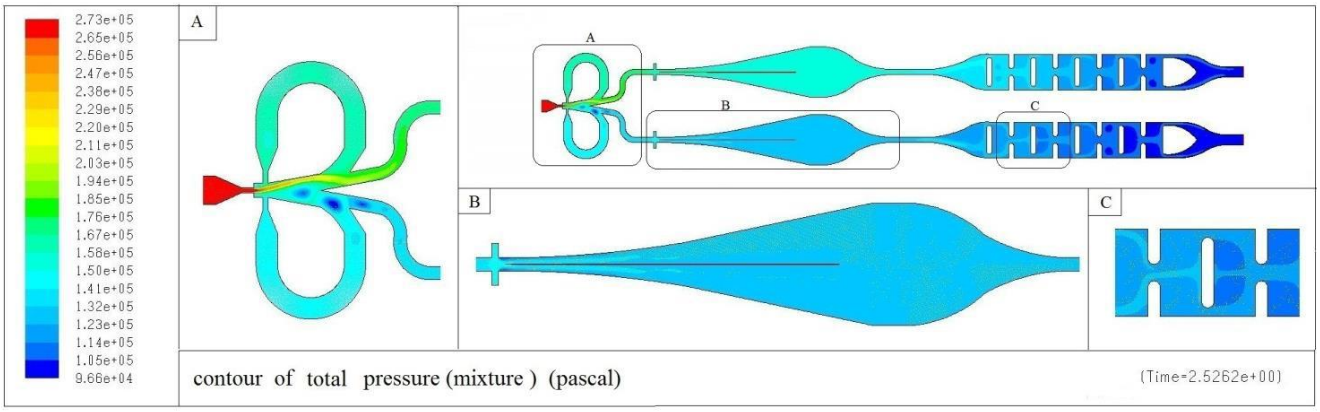


Fig.6. Contour of total pressure in the micro-mixer.

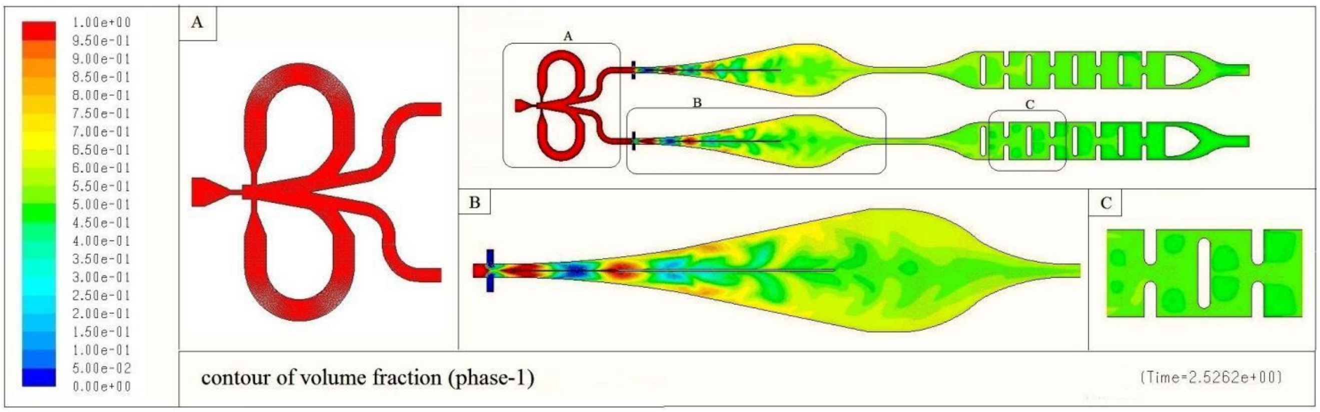
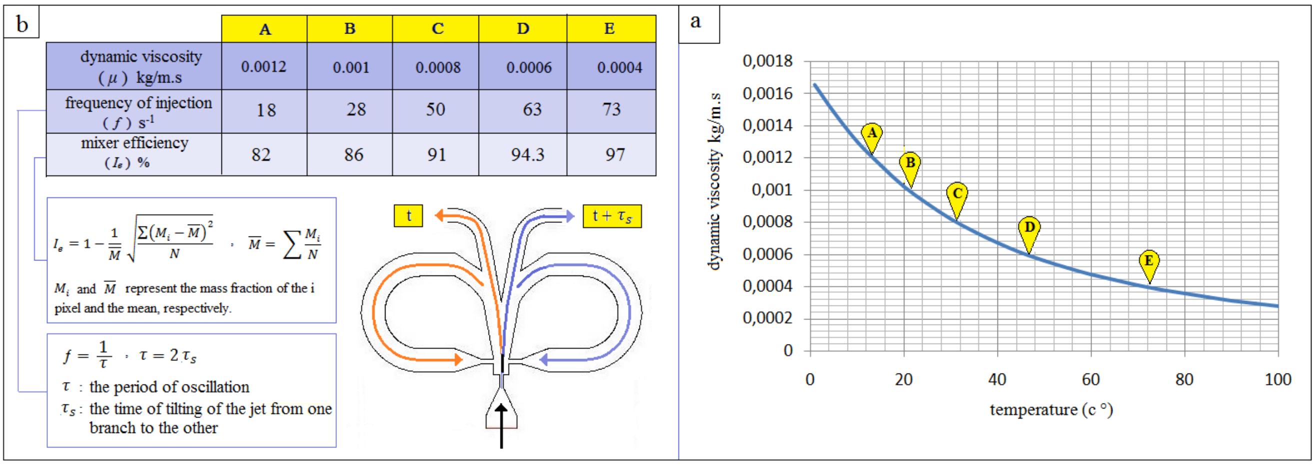


Fig.7. Contour of the mass fraction in the micro-mixer.

It will be noted (**Fig. 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. 7**), 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 micro-mixer due to oscillation of fluid within the micro-oscillator.

3.4 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.8.(a))**, 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.



b	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

Fig8. (a) Curve of the viscosity variation Dynamics of water as a function of temperature; (b) Efficiency of the micro-mixer for different injection frequencies.

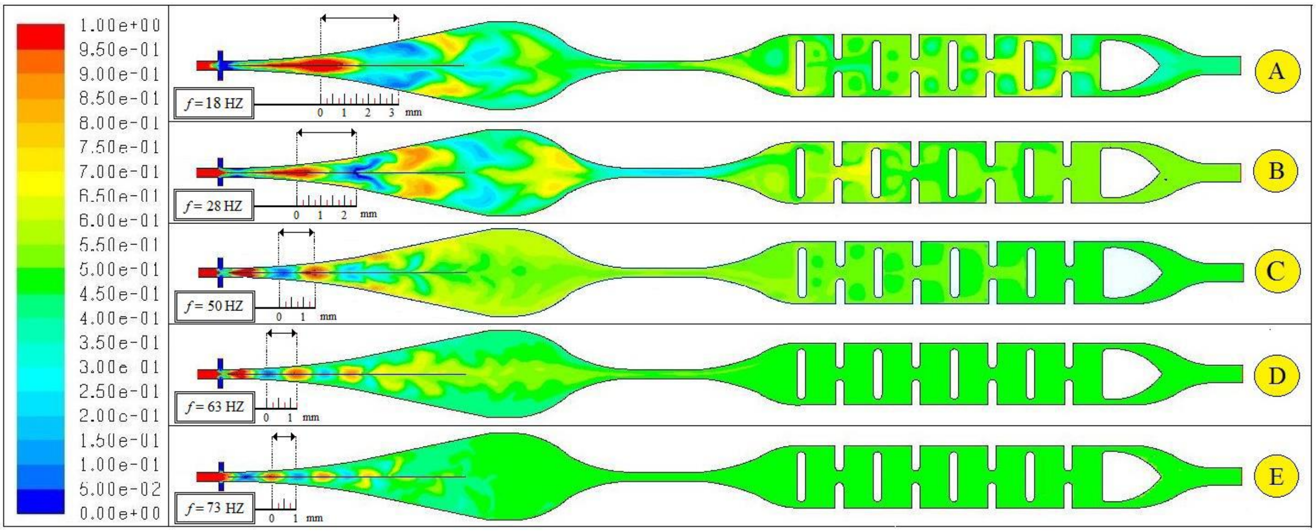


Fig.9. Contour of the mass fraction of micro-mixer for different frequency injections.

(**Fig.8. (b)**): 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.9**): Note that 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. 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:

$$\tau_m = \frac{L^2}{D} \quad (5)$$

L : distance between two fluids to be mixed (m)
τ_m : the time required for mixing (s)
D : diffusion coefficient ($cm^2 s^{-1}$)

4.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 micro-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 unsteady movements generated by a micro-oscillator has a clear influence on the efficiency of the mixture despite the regime of the flow is highly laminar.

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