MICRO - OSCILLATOR: PASSIVE PRODUCTION AND MANIPULATION OF MICRODROPS

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Abstract- A numerical and experimental studies of passive micro drops production have been presented. This paper focuses on the modeling of micro-oscillators systems which are composed by passive amplifier without moving part. The micro-system modeling is based on geometrical oscillators form. An asymmetric micro-oscillator design that is based on a bistable fluidic amplifier is proposed by .Foster and khelfaoui. The characteristic size of the channels is generally about 35 microns of depth. The numerical results indicate that the production and manipulation of microdrops are possible with passive device within a typical oscillators chamber of 2.25 mm diameter and 0.20 mm length when the Reynolds number is Re = 490. The novel micro drops method that is presented in this study provides a simple solution about the production of microdrops problems in micro system. We undertake an experimental step. The first part is based on the realisation of sample oscillator; the second part is consisted of visualization, production and manipulation of microdrops.

Keywords- modelling, miscible, micro drops, production, oscillator sample, capillary.

I. INTRODUCTION

In the biochemical areas, the reactions are performed in bio-MEMS require production of microdrops. There has been an increasing interest among both biologists and researchers at the medicinal laboratories in the study of mixtures on a metric and micro scale [9]. In the context of the IMEMS, a numerical study on static micro oscillators and the possible prospects for technical adapted solution of micro systems have been presented. Micro device can be classified under two categories, passive and active. Whereas the external perturbations are introduced in the active micro drops to enhance the geometrical form, the process in the passive oscillators completely relies on multiphase. The behavioural study of the micro flow oscillators enables the prediction of the state of the drops and the efficiency of device. Within the last decade, the world of the "bio" micro technology has grown up more to many universities and private groups which have developed micro systems for biomedical and chemical applications. Fluidic elements with no moving parts are able to realize logic (yes, no, and, or...) or proportional (signal amplification) functions, The characteristic size of the channels is generally about a few tens of microns. This miniaturization involves series of fundamental problems related to the mechanical fluid. Indeed, at these scales, the fluidic flows are laminar [1]. The working principle of this device is consisted in disturbing the flow of jets moving along the principal channel by the flow of oscillations which are generated by three pairs of lateral canals. The device is called micro injector. In these cases, the oscillators use special designed geometric configurations, identified by the absence of moving parts, to create an environment where self-induced, sustained oscillations will occur [2]-[3], they can be used as flow meters. A novel fluidic oscillator has been developed and tested by V.Tesar. He has made these oscillators attractive as micro reactor injection application.

A fast micro drop 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 literature describes significant number of devices that have been designed to improve the micro drops on a nanometric scale [3]-[4]- [5]-[6].

II. APROXIMATION OF THE OSCILATION FREQUENCY

The period of oscillations is determined by the switching time from the attachment wall to another and the transmission time through the feedback channel [3]-[4]-[5]-[6]; the frequency is determined by expression (1).

$$f = \frac{1}{(t_s + t_r)} \qquad (1)$$

A. Modeling oscillator for air flow

The oscillators are characterized by their flow evolution versus pressure [1]. Two main advantages of micro-fluidic can be highlighted: very small analysis devices reduce the time of analysis and volume of components needed. The model oscillator is similar to V.Tesar's model with major modification [6]. Its profile is presented in Fig 1. The geometry of the mixer can be separated into two regions, the mixing and the control region. The secondary flow through the control orifice perturbs the aspired flow and the principal flow.

B. Description of the Geometries Model

We reuse our results, presented at the ASME 2010 congress, the simulation results of air flow in an

oscillator geometry without second feedback, it is a configuration with one injector only with events for every injector, that dimension is mm)6.10 24.32(× . The output orifice size is equal to 0.50 mm [8].

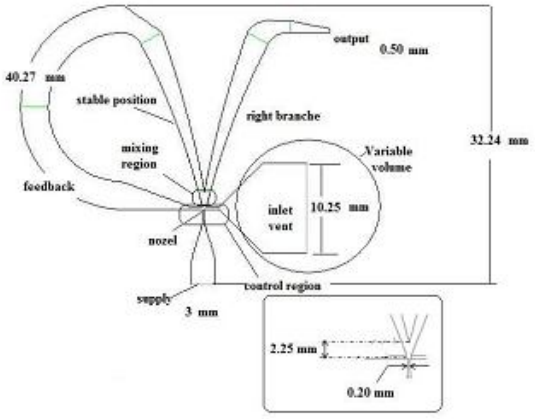


Fig 1: The fluidic oscillator injection mixer system. The initial configuration first case [8]

The pressure applied on the valve supply is supposed to be positive. A jet issuing from a nozzle and expanding between two inclined walls will attach to the less inclined one or to the wall which is closer from the jet axis Fig 1. The jet will oscillate, and the element will behave as a fluidic oscillator. A plane oscillator of constant depth is made with a square tube. Such plane oscillators are simulated by a fully CFD approach.

C. Hypotheses

The simulation of the micro-injection systems is obtained with several hypotheses:

1- air and laminar regime
2- Incompressible ideal gas flow.
3- Inlet pressure 2 × 105 Pa. outlet pressure 105 Pa
4- Results are presented for the Re=300 at the nozzle.

D. Hydrodynamic Results

On the first results case geometry Fig 1, we present the following obtained results for monostable oscillator. The relationship f (1/V) is linear, Fig 2; the injector form is supposed the Volume layout. This linear relationship for a given supply pressure is presented below.

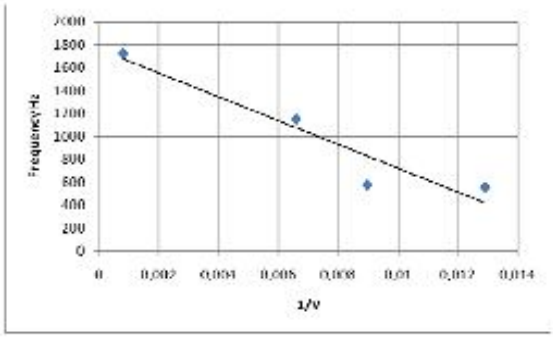


Fig 2: The oscillation frequency f versus 1/V. [8]

III. MICRODROPS PRODUCTION

A. Description

Modeling and simulation offer an important complimentary means to understand droplet dynamics and optimize device design and operation. The interface tracking method is a sharp interface approach, in which the interfaces are assumed to be infinitely thin, i.e. zero thickness. A set of governing equation are applied to each phase or component, and the interfacial conditions are used as boundary. Through iteration; the velocity of the interface is defined, and the interface then moves to a new location ready for the next time step. By this manner, the computation continues, and the interface is exactly tracked. This approach can provide very accurate results for cases without sever topological changes, and it forms the foundation of the front tracking methods. However, such an approach encounters singularity problems when significant topological changes (e.g., breakup and coalescence of droplets) occur. In these situations, artificial treatments or ad hoc criteria are required.

The VOF method uses the volume fraction of one fluid phase or component (denoted as C) to characterize the interface (here, we refer to two immiscible fluids). In the bulk phase (i.e. a pure fluid), C is equal to zero or unity; in multi-fluid computational cells, 0 < C < 1. In general, the VOF method consists of three major steps: the interface reconstruction algorithm, which provides an explicit description of the interface in each multi-fluid cell based on the volume fractions at this time step: the advection algorithm, which calculates the distribution of C at the next time step by solving an advection equation (2).

$$\frac{\partial C}{\partial t} + u \cdot \nabla C = 0 \qquad (2)$$

Generally, the effect of interfacial tension force is incorporated into the momentum equation (3) using the continuum surface force (CSF) model of [9]

$$\rho \frac{\partial u}{\partial t} = -\nabla p + \eta \nabla^2 u - F_s + \rho g \qquad (3)$$

The corresponding dimensionless number is the capillary number which compares the surface tension forces with the viscous forces.

$$Ca = \frac{\eta u}{\sigma} \qquad (4)$$

Where the viscosity of continuum phase is usually used, generating uniform droplets is an important step of achieving micro droplet functionalities. Using pressure as driving force to generate droplet is one of the fastest and commonly used methods. Many micro fluidic devices have been designed to apply pressure to generate uniform droplet, including geometry dominated device [10]-[11], flow focusing devices; T-junctions [9] and co-flowing devices [12]. For device design optimization and operation, it is

important to understand the underlying mechanism of droplet generation processes in micro channels. T-junction is one of the most frequently used micro fluidic geometries to produce immiscible fluid segment (plugs) and droplet. Although this approach has been widely used, the currently available information is still fragmented due to differences in channel dimensions, flow rate, fluid proprieties and surface materials.

B. Simulation results

We simulate the dynamics of micro droplets flowing into oscillator consisting of complex geometrical form as shown in Fig 1.

C. Hypotheses

The simulation of the micro-injection systems is obtained with several hypotheses:

- liquid and laminar regime
- Incompressible.
- Inlet pressure 2 × 105 Pa, outlet pressure 105 Pa
- Results are presented for the Re=300 at the nozzle.

We choose generating drops with oscillator. In this step, the introduction in the principal supply water and in the control input oil with surface tension coefficient is equal to 0.02888 N/m of 20°C (Surface science instruments from Data Physics Instruments). The PISO (pressure-implicit with splitting of operators) scheme is applied for pressure-velocity coupling. We used a second order Euler scheme for the transient terms. The numerical stability is ensured by setting the maximum courant number to 0.25. First results of masse flow rate and masse faction phase of oil are presented below respectively to Figs: 3, 4, 5, 6.

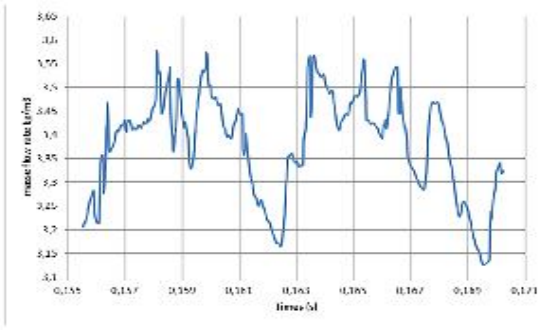


Fig.3: The output masse flow rate for the surface tension coefficient that is equal to 0.028 n/m.

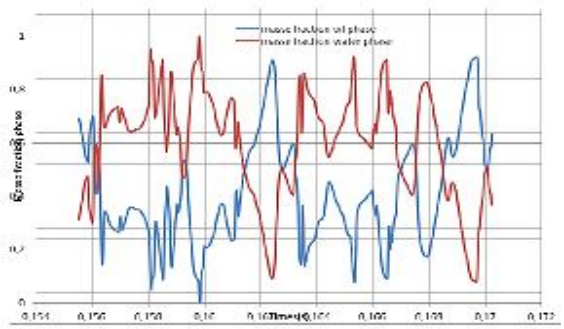


Fig 4: The output massefraction oil phase for the surface tension coefficient that is equal to 0.028 n/m.

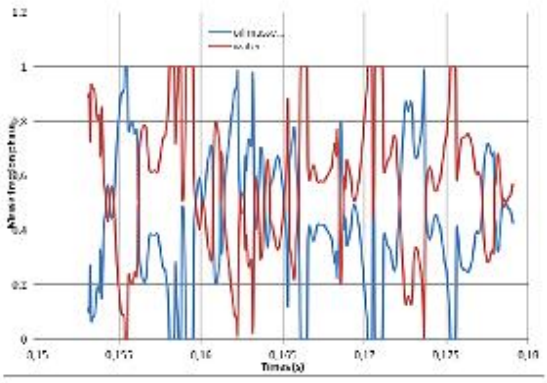


Fig 5: The output massefraction oil phase for the surface tension coefficient that is equal to 2.10-1 n/m.

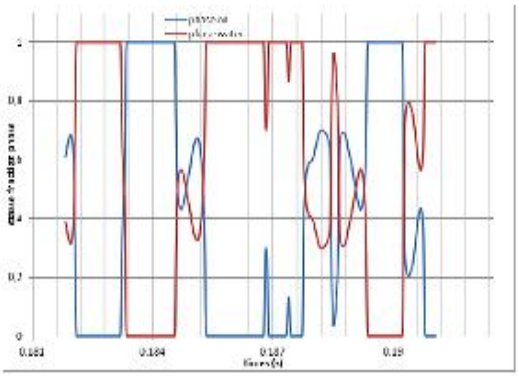


Fig 6:The output masse fraction oil phase for the surface tension coefficient that is equal to 0.9 n/m.

Masse flow rate present an harmonical signal without stable maximal and minimal amplitude. We constat if fluids are liquide the signal is realy difficut to estimate frequency compared as gazeous flow. but Transmation fourier feting calculate values frequency for masse fraction oil phase signal. The non dimensional numbers characterize flow phenomenon through the oscillator; capillary, Reynolds and Weber numbers are reported in table n°1.

TABLE 1: THE CAPILLARY, WEBER AND REYNOLDS NUMBERS VARIATION.

σ (n/m)	0.9	0.4	0.2	0.1	0.028	2.10^{-3}
$Ca*10^{-4}$	19	32	88	176	1051	8835
Re	325	319	321	334	332	322
$We*10^{-3}$	1063	1406	2836	5878	34919	284480

We adress in the following Fig, the variation frequency depending on the surface tension.

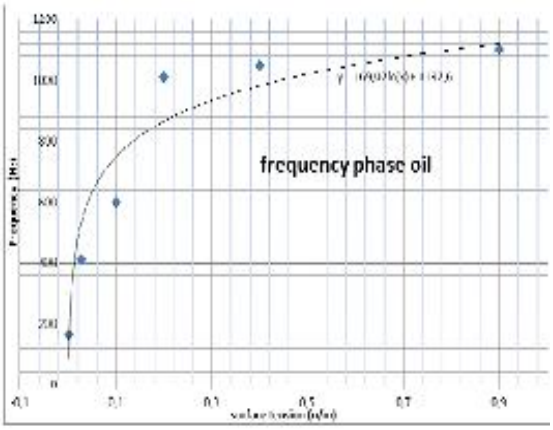


Fig 7:The frequency of masse fraction oil phase.

In the following Fig, we present the effect pressure of the frequency masse fraction oil phase .we reduce the principal supply pressure and undertake the secondary alimentation constant pressure.

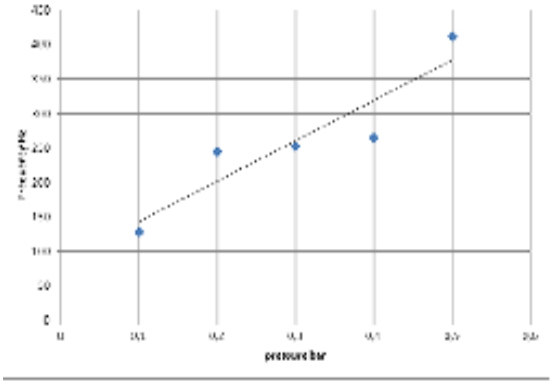


Fig 8: The frequency of masse fraction oil phase for the surface tension that is equal to 0.028 n/m.

IV. INTERPRETATION

The presenting results are obtained with several hypotheses, similar to the first case with gaseous flow. However all supposition required laminar flow. In literature all results concerning micro drops simulation allow increasing pressure estimate at mili-bar. The Reynolds number for all cases is equal to 320. More specially, we simulate low Reynolds number flows (Re =320) with 0.002 <Ca<0.9, where we describe the capillary number evolution based on the viscosity and the average velocity in the main channel, which is the ratio of viscous stress over the restorative Laplace pressure P.Day 2012. The frequency of masse flow signal is linear for the surface tension that is equal to 0.0028 N/m, Fig 9. The frequency of oil discrete phase evolution versus of surface tension coefficient is shown in the Fig n°8, presents important results. The frequency becomes stable when surface tension coefficient is upper than 0.2 N/m. The Figs 9, 10 represent the evolution respectively to the capillary and Weber numbers.The following Fig refers to the critical capillary number in which the droplets get detached from the holes.

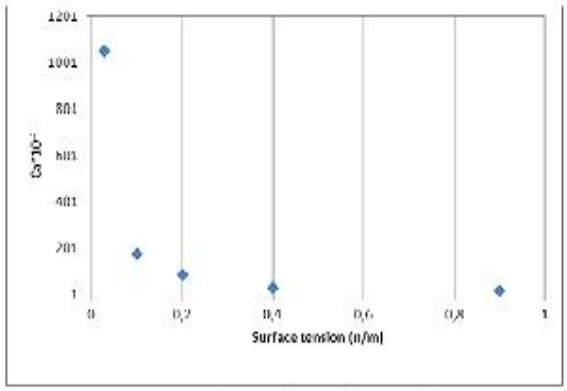


Fig 9 : The Capilary number

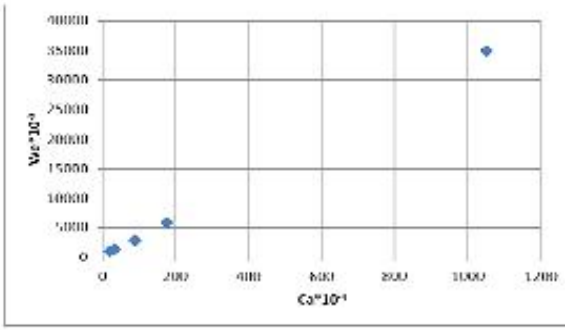


Fig 10: The Weber number

V. EXPERIMENTAL FIRST STEPS

In this phase, we undertake the realization of a micro oscillator samples for experimental protocol. The first samples which were produced in our laboratory are based on geometrical size from our first work published in ASME 2010 congress [8]. The simple method consists of chemical development process and sensible photo plaque exposition in ultraviolet rays. The geometrical form of sample is reported between model and plaque. After that we can plunge the plaque in a solution of perrochlorure of metal. The sample is consisted of plaque and glass showed in the following Fig.



Fig1: The first sample oscillator without glass covers (a), nozzle size (b), realized in ISC team, ENERGARID laboratory.

The following photo presents an experimental process, in which it describes the visualization system. Two peristatic pump supply variable inlet liquid flow; no miscible liquid (water and oil) are administrated in the oscillator device. The mass flow rates variation is between 0.36 and 0.9 milliliter/s.



Fig2: Experimental setup

The results of the first experimental visualization are showed in the Fig 3.



Fig3: Experimental visualization of micro drops

The initial contact of two miscible liquids is presented in the photo 3 (a), we observe the detachment of the first micro drop. In the Second steps the micro drop is oriented in large zone of oscillator.

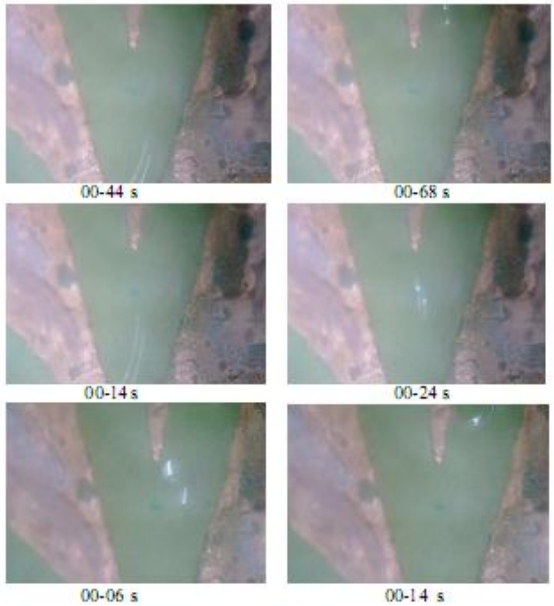


Photo 4: Experimental visualization of micro drops. The frequency apparition of micro drops is equal to 10 Hz for maximal mass flow 0.85 milliliter /s.



Photo 5: Experimental visualization of micro drops. The frequency apparition in the left branch of micro drops is equal to 69 Hz for minimal masse flow 0.36 milliliter/s.

CONCLUSION

The development of this micro fluidic oscillator system was mainly focused on the production simulation of micro drops. The oscillator model that is proposed to produce micro drops without moving part is an important step. The frequency of discrete phase frequency depends sensitively on micro flow frequency. We can adjust this parameter if we manipulate pressure supply parameter. For surface tension the coefficient is equal to 0.02888 N/m, the Capillary number and Weber number estimate respectively, 1051 10-4 and 34,919, the discrete phase frequency depends also on the surface tension. In the second phase of this work we must undertake experimentation of sample oscillators to validate our results. This Work presents an opportunity especially for the chemical engineering. We undertake an experimental visualization of micro drops production with oscillator device. The first results of visualization micro drops production indicate difficulties of realization micro device systems. In the experimental setup we reduce micro flow supply to maintain integrity of oscillators. The micro drops are oriented in the left and the right branch of oscillator. The frequency of micro drop production is low estimated than 20 Hz. Our purpose in the future is using an indicated experimental material to undertake experimental measurements.

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REFERENCES

[1] P. Tabeling, Introduction à la micro fluidique, Collection Echelles, Belin, 2003

[2] Foster, C.A.Parker “Fluidic Components &Circuits”. 1970, John Wiley & Soon Ltd, ISBN 0471267708, pp 265-273

[3] U.Gebhard, H.Hein and U. Schmidt. “Numerical investigation of fluidic micro-oscillators” J.Micromech, Microeng. 6. (1996) pp 115-117.

[4] Eliphas Wagner Simões, Rogerio Furlan, Roerto Eduardo Bruzetti Leminski,”Numerical Oscillator For gas flow control and measurement J flow measurement and instrumentation 16(2005) pp 7-12

[5] V.Tesar, J.R.Tippetts, Y.Y.Low “Oscillator mixer for chemical microreactors” 9th international symposium on flow visualisation, 2000, 298.1-298.7

[6] W.Gerhard “Fluidic temperature sensor investigation for high gas temperatures”, 1969. AGARDograph 135.

[7] R. Khelfaoui, S. Colin, R. Caen, S. Orieux, and L. Baldas, "Numerical and experimental analysis of monostable mini- and micro-oscillators," Heat Transfer Engineering, 30(1–2):121–129, 2009. Copyright C __ Taylor and Francis Group, LLC

[8] B.Dennai, R.Khelfaoui,, B.Benyoucef, « Theoretical study : flow control mono and bi-stable fluidic device for micro-injection system », août 2010, séminaire A.S.M.E “8th International Conference on Nanochannels, Microchannels and Minichannels, August 1- 5, 2010, Montreal, Canada.

[9] Philip Day, Adreas Manz, Yonghao Zhang "Microdroplet Technology, Principles and emerging Application in biology and chemistry". ISBN 978-1-4614-3264-7. 2012. Springer.

[10] Sugiura. S. Nakajima. M. and Seki. M. (2004) "Prediction of droplet diameter for microchannel emulsification :Prediction model for complicated microchannel geometries," Ind. Eng. Chem. Res. 43, 8233.

[11] Yasuno. M. Sugiura. S., Iwamoto. S. Nakajima. M. Shono. A. and Satoh. K. (2004) "Monodispersed microbubble formation using microchannel technique," AIChE J. 50, 3227.

[12] Hua. J. Zhang. B. and Lou. J. (2007) "Numerical simulation of microdroplet formation in coflowing immiscible liquids," AIChE J. 53, 2534.

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