Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 18 (2012) 571 – 580

Energy Procedia

Flow control mono and bi-stable fluidic device for micromixer-injection system

Brahim DENNAI[a], Rachid KHELFAOUI[a], Boumédiène BENYOUCEF[b]
and Asma ABDENBI[c]

[a] *Laboratory ENERGARID, University of Bechar, B. P. 417, 08000 Bechar, Algeria*
Tel.: 213 49 81 55 81/91, fax: 213 49 81 52 44
[b] *Laboratory URMER, University of Abu Bakr Belkaid, Tlemcen, Algeria*
[c] *University of Bechar, B. P. 417, 08000 Bechar, Algeria*

Abstract

Fluidics is a new technology arising from a re-appraisal of a very old technology, namely fluid power and its control. Fluidic technology based on natural oscillation phenomena is a relevant topic in several strategic areas. This technology of using the flow characteristics of liquids or gases to operate a control system is fairly old; it was in the 1960s that researchers started to use fluidics.

This paper is focused on the modeling of a microinjection systems composed of passive amplifier without mechanical part. The micro-system modeling is based on geometrical oscillators form. An asymmetric micro oscillator design based on a monostable fluidic amplifier. Several configuration of associate device are simulating to found adequate logical signal form. The characteristic size of the channels is generally about **a** few hundred of microns

Click here and insert your abstract text.

Keywords: fluidics, micromixer, injection system

Nomenclature

f	frequency (Hz)	t_s	switching time (s)	$\bar{M}$	mass fraction average
t_t	transmission time (s)	M_i	mass fraction of i pixel	L_O	outlet length (m)
γ	constant of gas 1.4 of air	r	gas constant (j/K.mole)	T	temperature (K)
$Di_{,m}$	the diffusion coefficient	Ji	the diffusion flux (w)	q	mass flow (kg/s/m)
Δt	time steep (s)	Re	Reynolds number		

---

* Corresponding author. Tel.: 213-49- 81- 55- 81/91; fax: 213- 49- 81- 52- 44.

E-mail address: dennai.univ@yahoo.fr

1876-6102 © 2012 Published by Elsevier Ltd. Selection and/or peer review under responsibility of The TerraGreen Society.
doi:10.1016/j.egypro.2012.05.069

1. Introduction

Within the last decade the world of the "bio" micro technology has growth up, more to many university and private groups which have been developing micro systems for biomedical and chemical applications. Fluidic elements with no moving parts, able to realize logic (yes, no, and, or...) or proportional (signal amplification) functions,

Were widely studied in the 1960s [1] the characteristic size of the channels is generally about a few tens of microns. This miniaturization involves series of fundamental problems related to the fluid mechanic. Indeed, at these scales, the fluidic flows are laminar [1].

The working principle of this device consists in disturbing the flow of jets moving along the principal channel by flow oscillations 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, make these oscillators attractive as micro reactor injection application [9]

2. Design and operation of the oscillator description

Micro oscillator were obtained from wall attachment micro fluidic amplifiers using a feedback loop from the outputs to the control input, figure 1, [2, 3, 4]

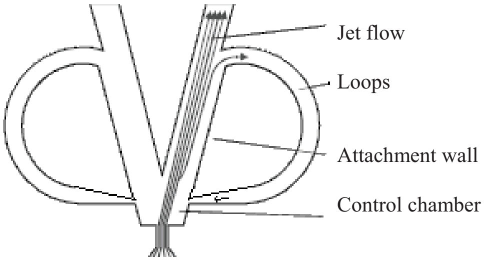


Fig 1. Bistable oscillator

The principle of oscillators is based on a fluid jet, which injected into the oscillator, bends due to small fluctuations towards one of the attachment walls. Some examples of systems and processes that might employ this technology include inkjet printers, blood-cell-separation equipment, chemical synthesis, genetic analysis, drug delivery, electro chromatography, micro-scaled cooling systems of electronic devices which generate high power. The fluid flow on the bent side of the jet is restricted and a low-pressure regime is created, which causes the jet to attach to the wall (Coanda effect) [7]

2.1 Approximation of the oscillation 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]; the frequency is determined by expression (1)

$$f = \frac{1}{2.(t_s + t_t)} \tag{1}$$

For liquids flow, generally the frequency of oscillation is strongly dependent on the switching time [4], is given in expression (2)

$$f = \frac{1}{2.(t_t)} \tag{2}$$

For gases, the frequency of a bistable feedback oscillator is function of the jet travel time, of the jet switching time, and the acoustic travel time [5]. In a rough approximation is given by expression (3):

$$f = \frac{\sqrt{\gamma.r}}{2.(l_b + 2.L_o)}\sqrt{T} \tag{3}$$

T temperature K, and γ=1.4 for air, r gas constant, l_b feedback loop length, L_o outlet length. The figure 2 represents three cases of frequency.

2.2 Valve modeling

The valves are characterized by their flow evolution versus pressure [6]. Two main advantages of micro-fluidic can be highlighted.

·

Tesla diode:

A Tesla diode [7] is similar to a valvular conduit. Its profile is presented in Figure 1.

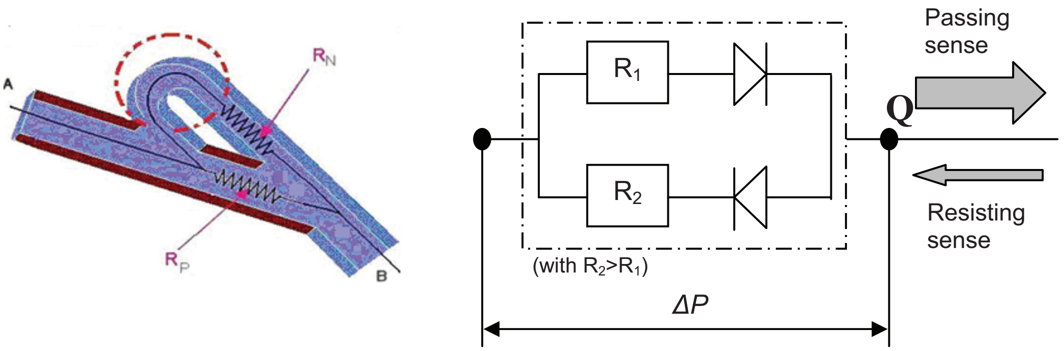


Fig 2. Fluidic Tesla diode Principe [7]

The basic structure of the diode of Tesla was invented by NIKOLA TESLA 1920. The flow in this diode is similar to two electric impedances in parallel figure 2. She allows a quasi-free flow of A towards B, but resisting in the sense (direction) set with a total equivalent electric resistance (RP + RN).

The geometry of the valve can be separated into three regions. In the region 1 and 3 the friction losses can be neglected and only acceleration losses have to be considered. For the flow, two analytic equations are implemented in order to take into account the asymmetric behavior of the micro-valve [7]

3. Description of the simulate geometries

We simulate the air flow in an oscillator geometry without feedback, it is a configuration with two injectors only with events for every injector, that dimension is $(13\times 4.4)cm$. The output orifice size equal 0.067 cm

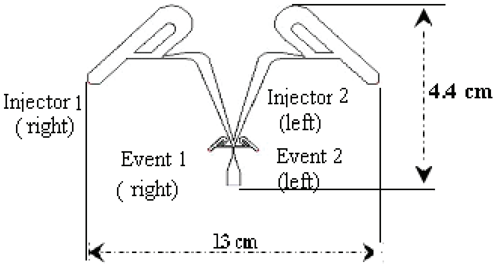
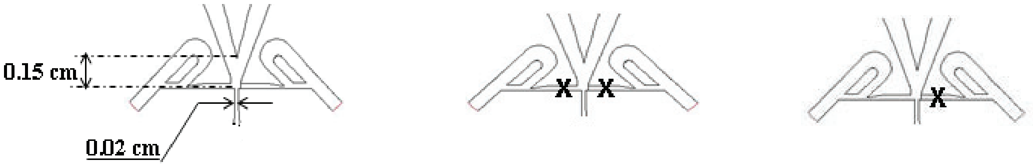


Fig 3. Fluidic oscillator injection system initial configuration first case



Case 1 Case 2 Case 3

Fig 4. Configuration simulate oscillator injection system

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 figure 4
The jet will oscillate, and the element will behave as a fluidic oscillator.

All following results are obtained for monostable oscillator. The relationship $f\,(1/V)$ is linear [8], the injector form is supposed the Volume layout. This linear relationship for a given supply pressure, the switching of the jet from the stable position towards the unstable position occurs as soon as an upper threshold pressure is reached inside the volume V.

Hypotheses:

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

- ✓ air and turbulent regime
- ✓ Incompressible ideal gas flow.
- ✓ Inlet pressure 2×10^5 Pa
- ✓ Next results are presented for the Reynolds number at the nozzle is around Re = 5632

4. Results first case injection system

On the first case geometry figure 4, we present the following results.

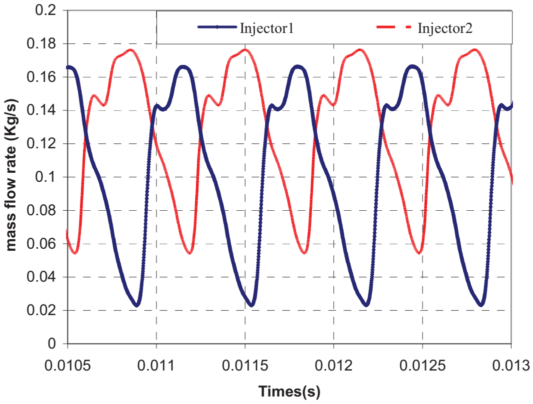


Fig 5. Mass flow output injection system signal

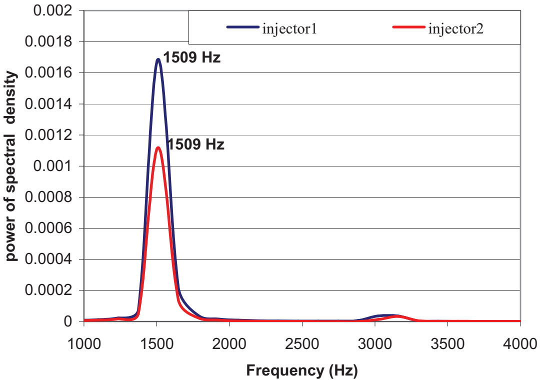


Fig 6. Spectral power of flow signal
case 1: two events open

The spectral analyses with Fourier transformation FFT describe the frequency oscillation of injection system for three cases studied, figures 6, 7, 8.

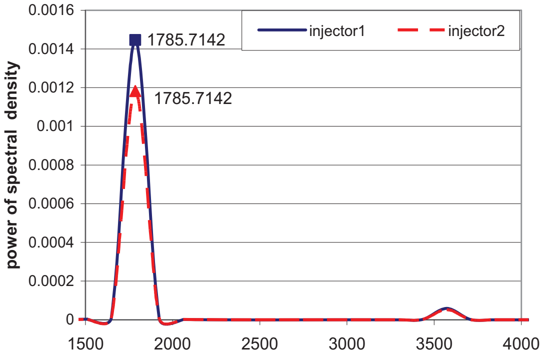


Fig 7. Spectral power case 2: two event close

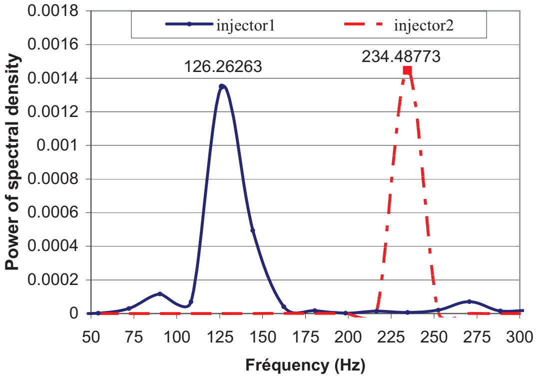


Figure 8: Spectral power of flow signal
(cas3: one event close)

The table 1 recapitulates the value of the frequencies obtainable for the three cases.

Table. 1: frequency of three case of first configuration

	case 1	*case 2*	case 3	
	Inject 1&2	Inject 1&2	Inject 1	Inject 2
F (Hz)	1509	1785.71	126.26	234.48

That means when the two events are closed, the frequency of signal obtainable has been reduced, but leaving one or two events opened gave the remarkable frequencies.

5. Species Transport Equations

When you choose to solve conservation equations for chemical species, FLUENT predicts the local mass fraction of each species, Yi, through the solution of a convection-diffusion equation for the ith species. This conservation equation takes the following general form:

$$\frac{\partial(\rho Yi)}{\partial t} + \nabla.(\rho \vec{v}\, Yi) = -\nabla.\vec{J}\, i + Si \tag{4}$$

In the first equation, Ji is the diffusion flux of species i, which arises due to concentration gradients. By default, FLUENT uses the dilute approximation, under which the diffusion flux can be written as

$$\vec{Ji} = -\rho D_{i,m} \nabla Y_i \tag{5}$$

Where Di$_{;m}$ is the diffusion coefficient for species i in the mixture.

5.1 *Estimation of the efficiency of mixing*

For estimating the mixing of index mixture, the following expression [9, 10, 11, and 12] is specified:

$$Ie = 1 - \frac{1}{\bar{M}} \sqrt{\frac{\sum (M_i - \bar{M})^2}{N}} \tag{6}$$

$$\bar{M} = \sum \frac{M_i}{N} \tag{7}$$

M_i , *and* $\bar{M}$ represent mass fraction of i pixel and average, respectively

5.2 Mixing results

The principal objective of our study is oriented to control injection system for mixing applications. This geometry constituted by monostable amplifier:

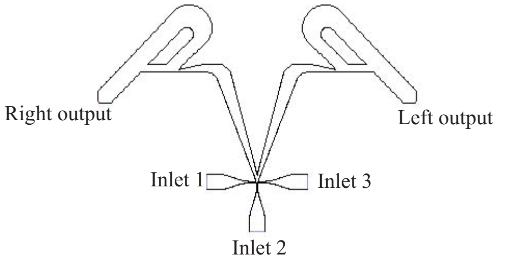


Fig 9. Fluidic oscillator for micromixer-injection system

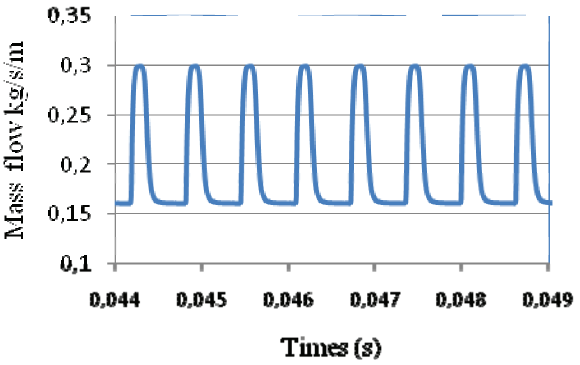


Fig 10. mass fraction distribution in output mixer system

Table2. Index mixture (left & right output)

Positions	Left output	Right output
Index mixture (I en %)	*99.466*	*99.895*

6. Results second case injection system

The principal objective of our study is oriented to control injection system for several applications. In this context we chose the following configuration figure 11. This geometry constituted by four injector with TESLA diode are assembled to obtain (1-3; 2-4) order control.

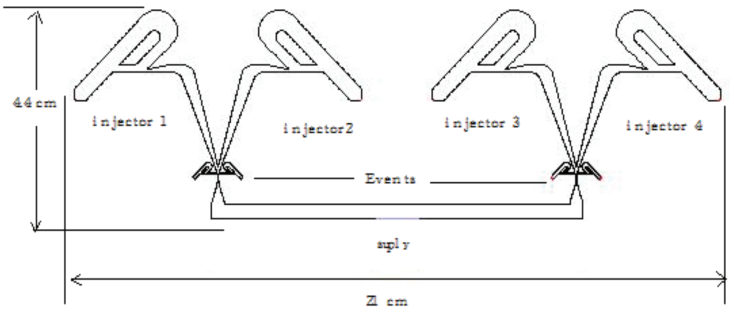


Fig 11. Fluidic oscillator injection system initial configuration second case

This configuration is allowed for injection system with four injectors. The orders of injection are more important a many filed application an engineering, for examples: fuel injection, or printer injection. Buts the principal problem is reversed flow, however many solutions with moved parts are possible, In this case we propose the fluidic diode, figure 2, without feedback and needles we can obtain injection jet and reduced reversed flow.

The mass flow signal output for second case injection system is presented at below figure 12.

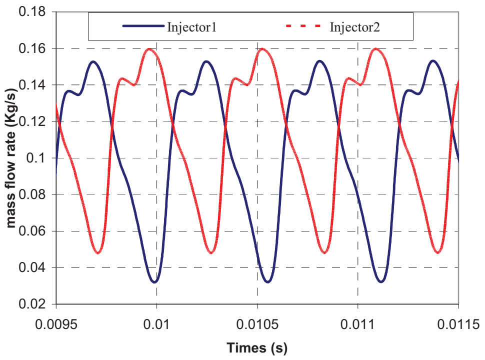


Fig 12. Mass flow output injection signal
(Second case injection system)

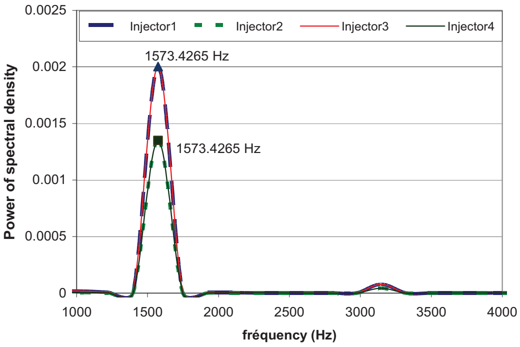


Fig 13. Spectral power of flow signal
(cas1: four events open)

The spectral form of signal output mass flow for four injector design principal frequency equal to 1.5 kHz.

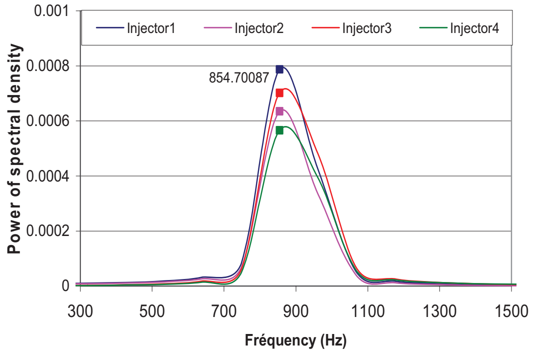


Fig 14. Spectral power of flow signal
(cas2: four events close)

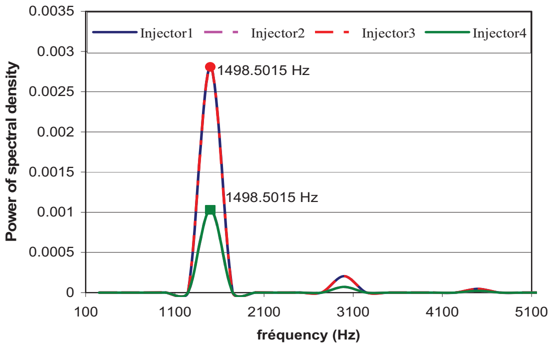


Fig 15. Spectral power of flow signal
(cas3: two events close)

The value of frequency obtainable for the case where the four events are opened is the more remarkable, that confirm the results for first case injection system.

The principal problematic in many engineering applications is residual reversed flow. Our objectives are minimizing reversed flow and control it with passive actuator

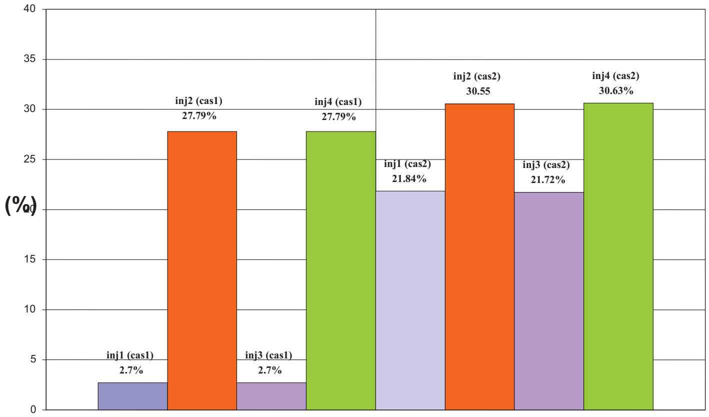


Fig 1**6.** Mass flow rate at closed injector in % for case 1 and case 2 second configuration

7. *Conclusion*

In this paper, a global modeling of a micro-injection system has been purposed in order to normalize its behavior. The reversed flow exist at down pressure with oscillation frequency between 0.1 kHz and 1.8 kHz

The performance of oscillating injection system mill metric size was simulated. The first results of theses numerical calculations indicate evaluation oscillating frequency of fluidic monostable oscillator, the next one consist of oscillating controlled injection system with four injectors.

Further simulations are currently underway for studying mixing capabilities for injection system.

A numerical study that the oscillation frequency is essentially controlled by a capacitive effect and that a secondary oscillation, due to the propagation of sound waves, disturbs the pressure signal without causing the jet switching [8]

All results, presents the response of monostable oscillator injection system. The oscillations exist for bistable oscillator if the feedbacks are connected at the system figure 1. The principal cause of these phenomena is, in the nozzle control the flow disturb the principal jet, and destabilize it. In the monostable oscillator the existence of one stable position and the capacitive effect create the oscillations.

In perspectives we propose the experimental study to confirm our results and optimize the geometrical injection system form principally the injection orifice and the nozzle splitter size.

References

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

[2] K.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 Simôes, 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] Samir Bendib, Olivier Français, “Analytical study of microchannel and passive microvalve "Application to Micropump simulator"

[8] 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

[9] V.Hohreiter, J. Chung, E. Cummings, T. Postlethwaite " Effects of system dimension on turbulence and micro fluidic" University of Florida Dept. of Mechanical Engineering P.O. Box 116300 / MEB 237 Gainesville, Florida 32611-6300 USA

[10] Yi-Kuen Lee, Patrick Tableing, Chiang Shih, and Chih-Ming Ho “ Characterization of MEMS-Fabricated mixing device “ International mechanical engineering Congress et exposition. Orlando, Florida, November 5-10, 2000, pp.505-511.

[11] Che-Hsin Lin1, Chien-Hsiung Tsai2 and Lung-Ming Fu3 “A rapid three-dimensional vortex micromixer utilizing self-rotation effects under low Reynolds number conditions”, J. Micromech. Microeng. 15 (2005) 935–943.

[12] R. Khelfaoui, B. Benyoucef, and S. Colin, "Micro mixture: sixe effect of micro mixing," in Technical Proceedings of 2007 NSTI Natotechnology Conference and trade Show - Nanotech 2007, vol. 3. Santa Clara, USA, 2007, pp. 201-204.