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Numerical Investigation of Flow Dynamic in Mini- Channel: Case of a Mini Diode Tesla

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Abstract Microfluidic systems are used and exploited in various fields, as they are highly specific and developed in their use. The micro devices are used in various analyzes of medical disciplines, chemical and other fields. Our research team "MAAt" within ENERGARID laboratory is in the process of triggered several lines of research in this area, the micro-mixing, separation of micro particles, droplet production. For that, we need tools and micro devices to study the phenomena.. In this work, we present a theoretical study and numerical simulation of micro device (micro diode Tesla). A Diode Tesla is similar to a heart valve conduit profile is shown in the following figure: In this simulation work, we will focuse the variation of geometrical parameters, the inside length lw (lw1> lw2> lw3), this study aims to optimize this setting to get a better efficiency. Then we will investigate the effect of the pressure variation on the volume flow.

Keywords: Mini channel, diode Tesla, efficiency, gas flow, microsystem.

Nomenclature

q_m: the mass flow rate of valve convergent/divergent (kg.s-1)

Q_P: the volume flow rate in forward direction (m^3.s-1)

Q_r: the flow rate in resistant sense (m^3.s-1)

Q_v: the volume flow rate (m^3.s-1)

E_{eff}: the efficiency of the valve (%)

L_w: the length of the inner conduit of the Diode Tesla(m)

α: the convergent angle

DELTA.P: Pressure difference (Pa)

div: divergent.

conv: convergent.

1 Introduction

The major issues of the microfluidics, we adapt them to the level of knowledge already acquired in the field of microfluidics: The physics of the miniaturisation (Principles, examples taken in the nature, MEMS, The chemical engineering, physics,

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colloidal), the hydrodynamics of the small systems (the micro-hydrodynamics, films, the micro jets…). Droplet in microfluidic (training, travel, crack and fusion of drops). The Hydrodynamic electro linear and non-linear. The mixture (diffusive mixing, chaotic, mixers micro-fluidic systems) [Chekifi, Dennai, Khelfaoui, and Maazouzi (2016); Tawfiq, Brahim and Khelfaoui].

The micro thermal transfers, the micro rheology, microparticles active and passive, the microfluidics to moderate Reynolds [Dennai, Bentaleb, Chekifi, Khelfaoui and Abdenbi (2014); Brahim, Rachid, Boumédiène and Asma (2012)], transfers to the walls, the flows in the natural environments.

The microfluidics is studying the transport of fluids in the micro channels of transverse dimensions ranging from a few microns to a few hundred micrometers, and characteristic length the millimeter or centimeter. It can be considered to be both a science (studies of the behavior of fluid in micro-channels) and a technology (manufacture of devices micro-fluidic systems for laboratories on a chip).

It is difficult to designer such or such a system as being the first circuit microfluidics never manufactured [KHELFAOUI (2007)].

Among the large number of application of microfluidics, two main directions can be distinguished the use of microfluidics as a tool for studying phenomena with greater accuracy, the gas flow in the Microsystems also offer a problematic, interesting in terms of the mechanics of fluid.

The first devices micro-fluidic systems have seen the light of day in the 1980s with a few isolated achievements, inspired by the use of new techniques of micro manufacturing developed for electronic components in order to achieve the systems thumbnails within which were circulating fluids. [PASCALINE (2010)].

The most remarkable Microsystems are micro pumps and micro valves. These are our goal in this article so we will study the application of the law of mechanics of fluid diode convergent / divergent and diode tesla, which we will exploit the CFD simulation code and we will define the characterization of the flow to obtain the best models.

2 Simulation of the geometric form

The miniaturization of processes is a promising way of intensification. because size reduction allows for devices characterized by large surface areas of mass exchange. The use of microwave technology is therefore particularly suitable for the implementation of physical processes limited by the fluids transfer in conventional devices. Very few studies focused to date on the impact of containment of runoff on the transport mechanisms in microsystems. The mini diode Tesla has become a very important tool in our research area because it has given us solutions to several problems during our simulation as the back problem with the micro injectors, and their application as an organ necessary in micro pump.

The simulated geometry is shown in the following figure:

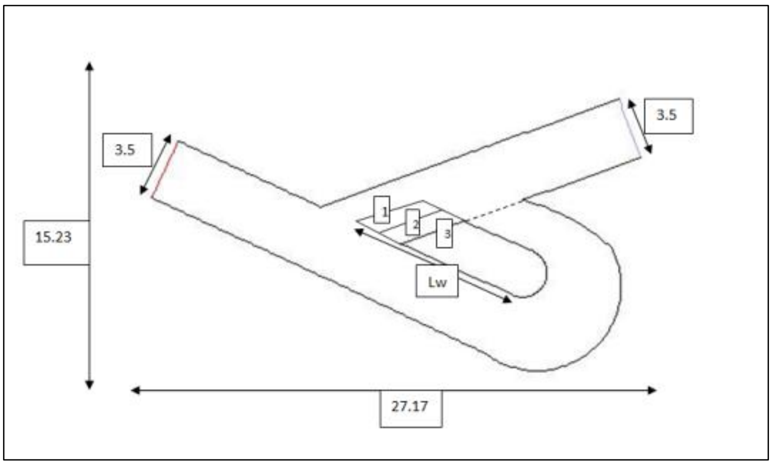

Figure 1: The simulated geometry of the Diode Tesla(dimensions are data in [mm])

The main purpose is to attempt to improve the efficiency of the valve, this efficiency is calculated from the following relationship [1]:

$$E_{ff} = \frac{I\ Qp - Qr\ I}{Qp} \quad (1)$$

In this study, we have started by a Diode test at different structures of channels (1-2-3), in order to study the influence of the length of the internal wall (LW), the simulation of a channel of Tesla for three LW (varies from 1 to 3), this study is for the optimization objective LW and to obtain the best efficiency in this Micro valve. (LW1>LW2>LW3).

The conduit valve allows fluid (air) to pass in one direction only.

3 The types of mesh

The mesh size is an important step in the numerical modeling, this procedure is performed by the software Gambit, this step to a direct influence on the calculation time and the results obtained.

There are three types of commonly used mesh:

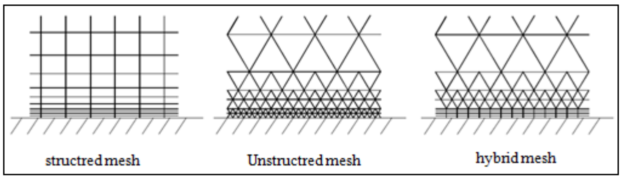

Figure 2: The different types of mesh size [Marc Anduze; Henri Camon. (2001)]

4 Description of the mesh size of the geometry

Before choosing the type of suitable mesh, we tried several types in order:

- To obtain the best solution and numerical model.
- To optimize the hydrodynamic characteristics of the Valve studied.

5 The mesh size of the Diode Tesla

The first step of the numerical study of this type of Diode is meshing geometry by the software Gambit, for this fact, we have meshed the field of fluid way similar, The geometry as well as the mesh obtained are presented on the following figure:

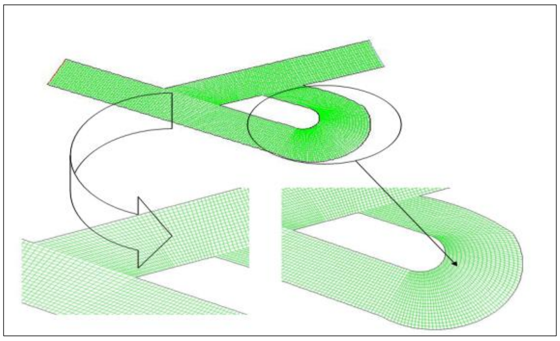

Figure 3: Definition of the mesh size of the Diode Tesla the type of mesh size used is the Structured mesh quadrilateral, with 5148 cells**.**

6 Assumptions of simulation of the diode tesla

The boundary conditions that we have imposed at the level of the input and the output of the field are the pressure conditions and with the same assumptions than the micro pump

characteristic parameters of the simulations are recalled in the following table:

Table 1: The simulation parameters

Mesh	Physical model	Numerical method
Quadrilateral/structured	Laminar flow Stationary compressible fluid (air) 2D	Pressure: -output pressure 1 bar

To study the effect of the variation of pressure on the volume flow rate compares the volume flow rate has different direction (forward direction and backward direction) as a function of the length of the wall Intern (LW) in a channel of the diode. We applies several values of pressure at the entry of the system.

7 Results and interpretation of the diode tesla(micro valve):

The convergence and stability of calculation are represented in the following figure:

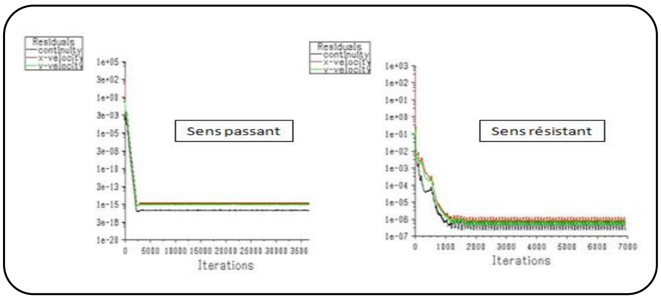

Figure 4: The test of convergence of the two meanings passing and resistant to (Δp=1bar)

The passing direction is the backward, the resistant direction is the forward.

7.1 The effect of the variation of pressure on the volume flow rate

In this part we compare the volume flow rate has different direction according to the length of the internal wall (lw) in a channel of the valve.

The results of volumetric flow obtained bitter the convergence of the calculation are summarized in the following table

Table 2: values of the pressure variation (Δp), and the volume flow rate in the two directions:

	lw1		lw2		lw3	
Direction / Delta P(Δp)	Passing sense $Q_v(m^3/s)$	Resistant sense $Q_v(m^3/s)$	Passing sense $Q_v(m^3/s)$	Resistan t sense $Q_v(m^3/s)$	Passing sense $Q_v(m^3/s)$	Resistan t sense $Q_v(m^3/s)$
1	0.84	0.58	1.02	0.62	1.14	0.64
1.2	0.93	0.64	1.12	0.68	1.25	0.70
1.4	1	0.69	1.21	0.74	1.35	0.75
1.6	1.07	0.74	1.29	0.79	1.44	0.81
1.8	1.13	0.78	1.37	0.83	1.53	0.85
2	1.2	0.82	1.45	0.88	1.62	0.90

The values of the previous table are plotted in the next curve:

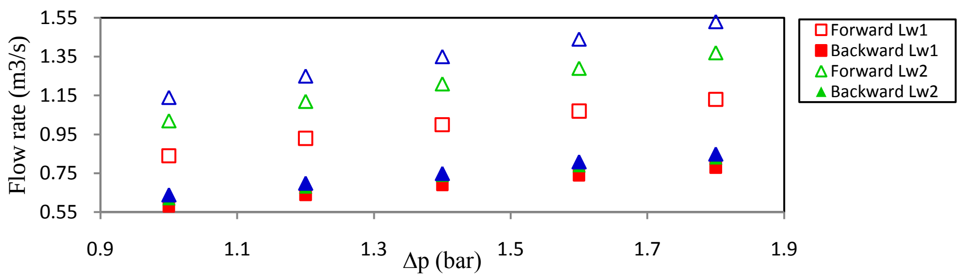

Figure 5: The curves for volume flow rate as a function of pressure difference to two direction.

In the graph above we note:

- The volume flow rate increases with the increase of the pressure variation
- The volume flow rate in the direction passing is greater by report to sense resistant (This note depends on the relationship of efficiency).
- The volume flow rate increases but the internal length of conduit LW decreases.

7.2 Calculation of the efficiency

The most important goal of this parameter is the determination of the geometrical structure which optimal allows you to eliminate the maximum return of the stream.

In the following table presents the values of the efficiency of this micro valves for (Δp=1bar and Δp=2bar) and LW1; LW2; LW3.

Table 3: The values of the efficiency

	efficiency		
	length Lw1	length Lw2	length Lw3
(ΔP=1bar)	30%	39%	43%
(ΔP=1.2bar)	31%	39%	44%
(ΔP=1.4bar)	31%	38%	44%
(ΔP=1.6bar)	30%	38%	43%
(ΔP=1.8bar)	30%	39%	44%
(ΔP=2bar)	31%	39%	44%

- It is very important to note that the optimal structure is that of the length LW3 corresponds to a linear extension of the input channel.
- The optimal efficiency of the structure LW3 is obtained for the variation in pressure between (43% and 44%)

7.3 Velocity vectors

The velocity vectors (expressed in m.s-1) in the median plane of the valve to two direction of flow is presented in the following figure:

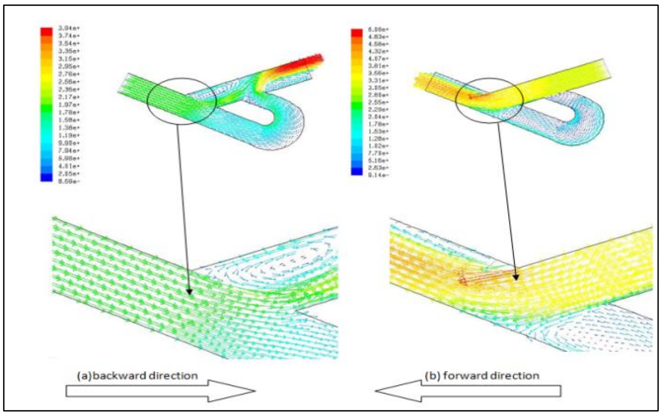

Figure 5: velocity vectors for the two directions of flow (Δp=1bar) and the internal duct of Diode Tesla length (LW3)

These distributions allow us to analyze the flow in both directions of fluid flow. In the forward direction vectors show that the flow lost its main course and change the direction of flow to the inner channel, secondly the flow in the direction resisting hold its initial meaning, recirculation enables increasing of the velocity vector in its sense.

7.4 Static pressure field

Figures (III-17-) represent the static pressure field in the microvalve (expressed in Pascal) in the median plane of the diode of the two flow under the pressure P = 2 bar for the inner channel of the diode tesla length (LW3)

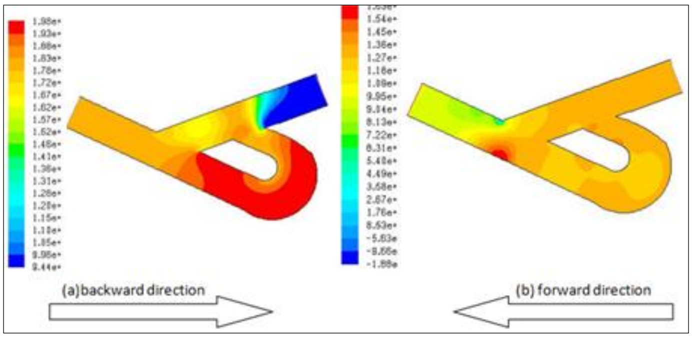

Figure 6: Field-of-static pressure for the two direction

We note in the above figures that the static pressure is important in the internal conduct for the direction passing and the meaning resistant the static pressure is decreased to the level of the output.

7.5 Proposed solution to reduce the problem of whirlpool

In this section, we suggest a solution to reduce the problem of vorticity (vortex) that we have found at Diode Tesla (Figure 7).

By modifying the geometric shape of the Diode Tesla (Figure 8), we have been able to reduce this problem.

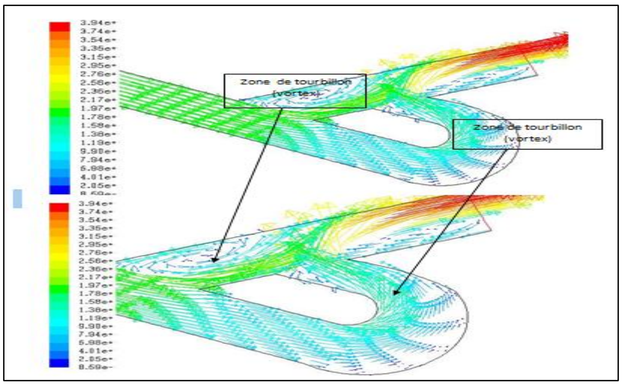

Figure 7: Geometry with the area of vorticity of Diode Tesla.

This change (on the angle α) has allowed us to eliminate the problem of vortex, but it has reduced the efficiency of the valve. What we propose in order to improve the performance is to optimize the other geometrical parameters (the length, LW, diameter of the Conduct….)

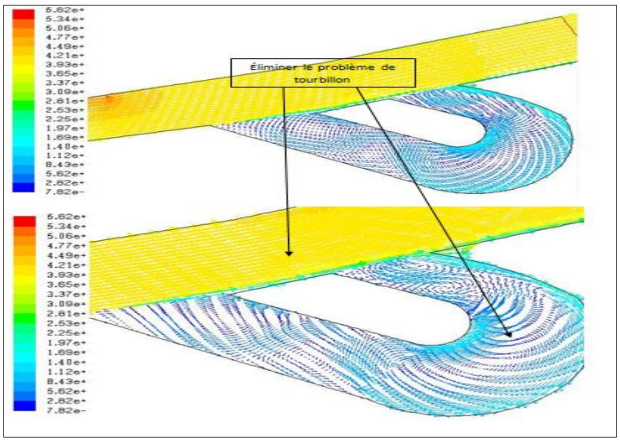

Figure 8: geometry after elimination of the vortex zone.

8 Conclusions

In this work, we were interested to numerical study of the mini diode Tesla, our goal was to determine how the geometric and hydrodynamic flows could influence the effectiveness of this type of diode. Regarding side geometrical parameters, the internal Lw length of the channel is a very important parameter that affected our results of our simulation and the digital flow diameter.

The complicity of the Tesla geometry is actually more difficult to model even if the flow regime is laminar, it was possible of encountering the vortex problem at critical locations of the geometry (in forward direction above) is it is due to the high pressures used (the boundary conditions) compared to the low-dimensional geometries used. The effectiveness of the Tesla diode in this case could reach around 43% for .DELTA.P = 1 bar and 44% for .DELTA.P = 2 bars, and what is remarkable at this level of scale.

This study has been able to be used to solve some problems encountered at our team, for example it served us to solve the problem back to meet at the mini injectors [Brahim, Rachid, Boumédiène and Asma (2012)].

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