JJMIE

Volume 5, Number 2, April 2011
ISSN 1995-6665
Pages 145 - 148

Jordan Journal of Mechanical and Industrial Engineering

Fabrication and Analysis of Valve-less Micro-pumps

Shireen Al-Hourani [a], Mohammad N. Hamdan[a], Ahmad A. Al-Qaisia[a], "Moh'd Sami" Ashhab[*,b]

[a] Mechanical Engineering Department, University of Jordan, Amman, 11942, Jordan

[b] Department of Mechanical Engineering, The Hashemite University, Zarqa, 13115, Jordan

Abstract

Micro-fluidic devices and their applications have received a lot of attention in recent years due to the fast growing progress in the field of Micro-fluid systems. Micropumps are one of the most important micro-fluidic components. In this work, a 2D simulation, using Computerized Fluid Dynamic CFD software, is performed to study the fluid coupling effect driven by piezoelectric actuation of a valveless micropump. The results show the relationship between inlet velocity, actuation value, the flow velocity and pressure inside the valveless micropump using laminar and turbulent models solutions.

Keywords: Micro-pumps; Fabrication; Piezoelectric actuation; Simulation.

1. Introduction

The measurements of Microelectromechanical systems (MEMS),such as piezoresistivity coefficients in germanium and silicon were published as early as 1954 which pointed the way for future pressure, displacement, and strain sensors design. The famous talk and respective publishing by Feynman (1960) revealed the possibilities of nanotechnology and micromechanical systems. The fabrication of resonant gate transistors, accelerometers [1], pressure sensors and silicon based strain sensors took place from 1960 to 1970, and these prototypes are generally considered as the beginning of MEMS device fabrication. Petersen (1982) was the first to publish the term micromachining, and also a survey of the respective current major techniques, with potential to be applied to mechanical systems. Intensive laboratory explorations took place during the next decades, followed by industrial success cases which became well known, like inkjet printer head [2], strain-based pressure sensors, mechanical resonators, accelerometers, gyroscope automotive sensors and others [1].

MEMS devices may include in the same structure the electronic and mechanical modules, encompassing sensors and actuators, with dimensions from the order of micrometers to millimeters. Today, they constitute one of the more promising and fast-growing new technologies. In a broad sense, miniaturization results in several new applications, beyond the reach of regular macro scale equipment. A good example is the development of solid state accelerometer used in the new automobile brake systems and air-bags [1,3], an application only made possible by the large scale production associated to microfabrication techniques [4-6].

MEMS, beginning as an application of microelectronic techniques to build mechanical systems, were first made in silicon. Nowadays, new materials and methods have been tested, looking for good electrical and mechanical properties and low costs. The common methods for MEMS manufacturing are based on micromachining and different kinds of lithography, including the very successful LIGA [7]. Micromachining has been largely used in industrial sensor production since the early 1980´s. It is based on different etching techniques used to shape forms on a crystal substrate [8]. LIGA involves the use of X-ray radiation to transfer a pattern to a polymeric thick layer and build metallic molds using some deposition technique. Using the metal structure built, plastic copies may be generated using several techniques [9]. Despite being very efficient, and a great improvement at the time it was developed, the main disadvantage of LIGA is yet a high cost due to mold manufacturing.

Recent progress in MEMS technology provides micro-fluid systems manufacturing and application pluralism further. The micro-fluid systems have the advantages of tiny size and easy to carry, also have high accuracy and short response time. They have quite great values, in fields like semiconductor, electronics, machinery, chemical analysis or biomedicine and laboratory chip development.

Among the micro-fluid control system components, they include micro-channels, micro valves, micro-pumps, micro-sensors and micro-actuators [9,10]. The micropump is one of the important components in micro fluidic systems since the micro-fluid control system requires a power to transport fluids which can provide considerably

[*] Corresponding author: sami@hu.edu.jo

precise flow rate. Therefore it becomes more popular in medical applications, such as micrototal analysis systems, Lab-on-a-chips (LOC), and micro dosage systems. Valveless micropumps are widely used due to their simple structure, durability and low maintenance. In recent years, wide verities of valveless micropumps have been developed [1].

Micropump systems usually include an actuating chamber and a valve. There is always a reciprocating cycle vibration in the actuating chamber and the flow channel; it is due to the volume variation of the chamber via moving membrane. A pressure drop is naturally formed when fluids are flowing. In accordance with its different actuating models, it can be divided into piezoelectric, electrostatic, thermo-mechanical, electromagnetic and shape memory alloy types. In addition, the valve can be divided into check-valve and valve-less types. The main function of the valve is to control the flow in a unique direction. The check-valve type acts as a blocking slice using a cantilever beam in the port. When the micropump is actuated there will be difference between the internal and external pressure of the micropump. The valve blocking slice in the channel turns on or off, making the fluid to flow in one direction without a reversing flow. Since the valve is operated frequently, it is easy to cause the valve material fatigue or disability to return to its original state which affects micropump efficiency and life-span. The valveless micropump is comparatively simple and stale [1].

In this work, Computerized Fluid Dynamic CFD software, is used to study the fluid coupling effect driven by piezoelectric actuation of a valveless micropump. The relationship between inlet velocity, actuation value, the flow velocity and pressure inside the valveless micropump using laminar and turbulent models is to be analyzed.

2. Valveless Micropumps

A particular type of micropumps which has received a lot of attention in recent years is the diaphragm based-valveless one shown schematically in Figure 1 [2]. The vibrating diaphragm constitutes the pumping mechanism, and among the different methods which may be used to actuate this vibration the piezoelectric is the well established one. Also this type of micropump design utilizes the dependence of pressure loss of the flow through the pair of fixed, and geometrically similar diffuser/nozzle elements at chamber inlet and outlet ports, on the direction of the flow through these elements to obtain a one way net flow over a cycle of diaphragm vibration cycle which constitutes the pump mechanism. During the pumping phase, namely, when the diaphragm is defected in downward direction, the flow from the pumping chamber is the nozzle direction at the inlet port and is in the diffuser direction at the output port. On the other hand during the intake phase of a pumping cycle, namely, when the diaphragm is deflected upward, the flow through the inlet port is in the diffuser direction and the flow through the output port is in the nozzle direction. Because, with diffuser/nozzle elements having same size and shape, the resistance (e.g, pressure loss coefficient)) to flow in the nozzle direction is higher than that in the diffuser direction a net flow from inlet to outlet is obtained over a pumping cycle.

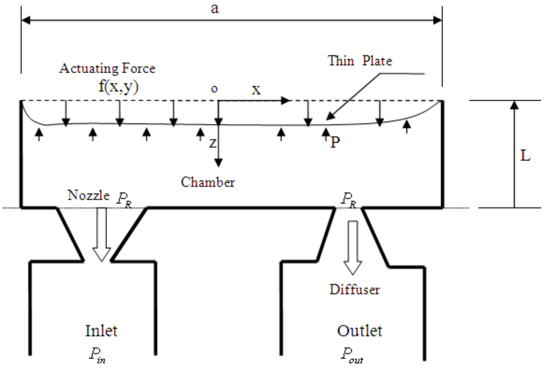

Figure 1. Schematic of the valveless micropump vertical cross section in supply mode.

3. Fabrication

Pump chambers and valves can be etched on silicon wafers using a Reactive Ion Etching (RIE) process to achieve precise control over the final etched shape in the valve regions. The micropumps have anodically bonded Pyrex membranes sealing the pump chamber and valves. All silicon/Pyrex assemblies were mounted on steel or aluminum backing plates, (using Crystalbond 509, Aremco Products, Inc.)[10].

The Reactive Ion Etching consisted of a number of independent components built up around a silicon pump chip. Membranes of stainless steel or brass shim stock could be used. A piezoelectric disk (PZT) can be bonded to the membrane with conductive silver epoxy. Pump bodies should be machined from *x* mm thick Plexiglas with a *y* mm diameter hole for the pump chamber, where *x* and *y* could be as per the design. Inlet and outlet holes, as needed (depending on the property being tested), should be drilled in the plexiglas. The membrane, pump body, and etched pump chip should be pressed together by an outer assembly. The Plexiglas acted as its own gasket.

4. The Flow Field

In developing fluid flow models for the micropump it is assumed that the density ρ and viscosity η of the modeled fluid are constant, in addition to not being affected by temperature and concentration. The governing equations of continuity and three-dimensional momentum can be expressed as follows:

$$\nabla \cdot \vec{V} = 0 \quad (1)$$

$$\rho \frac{\partial u}{\partial t} + \rho \vec{V} \cdot \nabla u - \eta \nabla^2 u + \frac{\partial p}{\partial x} = F_{E,x} \quad (2)$$

$$\rho \frac{\partial v}{\partial t} + \rho \vec{V} \cdot \nabla v - \eta \nabla^2 v + \frac{\partial p}{\partial y} = F_{E,y} \quad (3)$$

$$\rho \frac{\partial w}{\partial t} + \rho \vec{V} \cdot \nabla w - \eta \nabla^2 w + \frac{\partial p}{\partial z} = F_{E,z} \quad (4)$$

where u , v , w are the velocity components of $\vec{V}$, η is the dynamic viscosity of the fluid, ρ is the density of the fluid, and p is pressure. These equations describe the performance of fluids inside the micropump.

5. The Software Simulation

FLUENT, Version: 2d, dp, pbns, lam (2d, double precision, pressure-based, laminar);Release: 6.3.26; was used to analyze the valve less micropump with different actuation conditions and different inlet flow rate. The water was used as the main fluid to simulate the performance of the pump.

By making the inlet initial value to zero, the pressure and velocity contours as solved by FLUENT using equations [1-4] are shown in Figures [2-5].

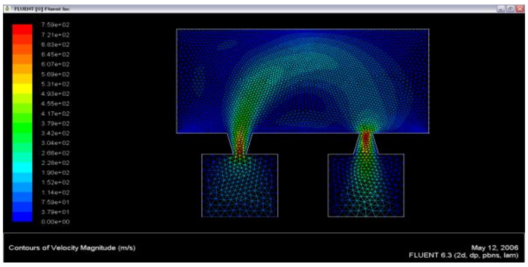

Figure 2. the velocity contour for v_{in} and actuation of 1000m/s, laminar.

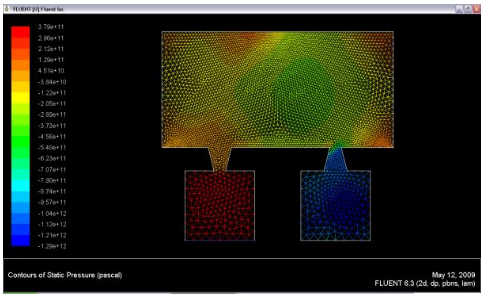

Figure 3. the Pressure contour for v_{in} and actuation of 1000m/s, laminar.

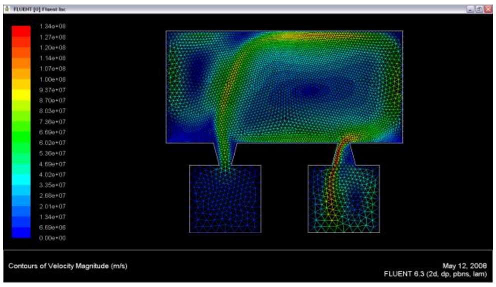

Figure 4. the velocity contour for v_{in} and actuation of 100 Km/s, laminar.

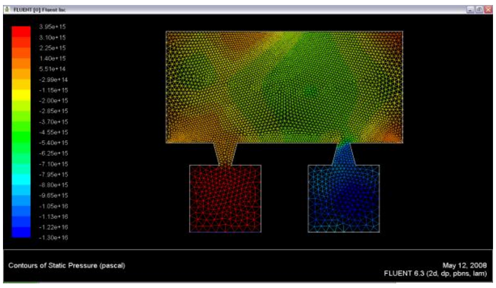

Figure 5.the pressure contour for v_{in} and actuation of 100 Km/s, laminar.

Solving for turbulent flow (K-ε model in FLUENT) gives the results shown in figures[6–11].

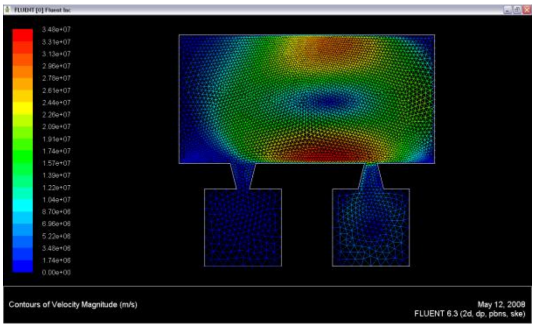

Figure 6. the velocity contour for v_{in} and actuation of 1000m/s, K-ε turbulent model.

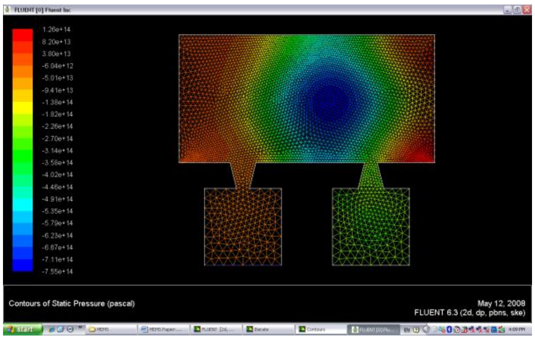

Figure 7.the pressure contour for v_{in} and actuation of 1000m/s, K-ε turbulent model.

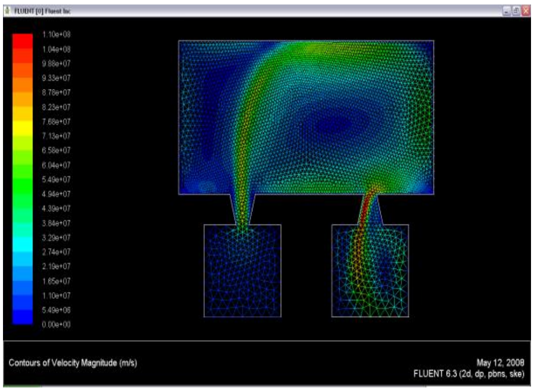

Figure 8.the velocity contour for v_{in} and actuation of 100Km/s, K-ε turbulent model.

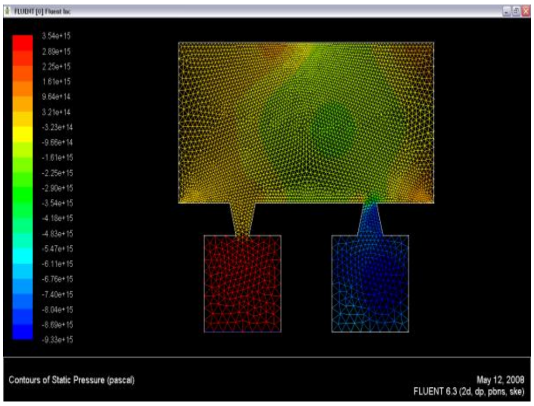

Figure 9.the pressure contour for v_{in} and actuation of 100Km/s, K-ε turbulent model.

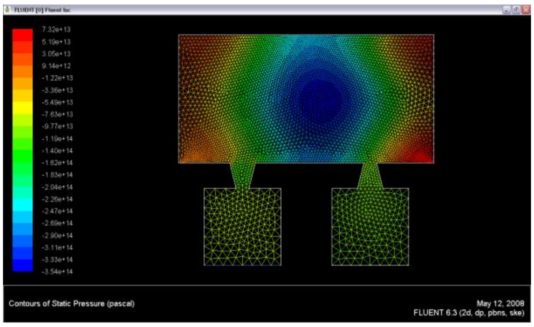

Figure 10. the pressure contour for v_{in} =0 and actuation= 100Km/s, K-ε turbulent model.

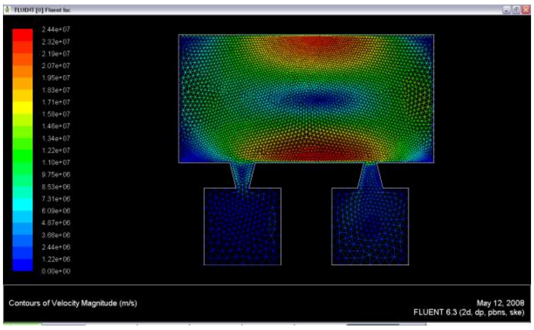

Figure 11. the velocity contour for v_{in} =0 and actuation= 100Km/s, K-ε turbulent model.

Figures(2-11)show the velocity and pressure contour with different boundary condition and we can easily notice the net flow from the nozzle to the diffuser, and how the membrane and inlet flow

affected the value of the flow velocity and pressure inside the pump chamber.

6. Conclusion

A 2D simulation was performed to study the fluid coupling of the micropump actuated by piezoelectric plate with variant working conditions. The results show the relationship between inlet velocity, actuation value, the flow velocity and pressure inside the valveless micropump using laminar and turbulent models solutions.

The study shows that the results are highly dependent on the boundary conditions.

References

[1] E. Nóbrega, C. Campos, “Deep UV lithography valveless micrtopump design and test”. ABCM Symposium Series in Mechatronics, Vol. 3, 2008, 586 - 594.

[2] P. Glynne-Jones, M. Coletti, N. M. White, C. Bramanti, S. Gabriel, “A Feasibility study on using inkjet technology, micropumps, and MEMS as fuel injectors for bipropellant rocket engines”. Acta Astronautica, Vol. 67, 2010, 194 – 203.

[3] K. Junwu, Y. Zhigang, P. Taijiang, C. Guangming, W. Boda, “Design and test of a high-performance piezoelectric micropump for drug delivery” Sensors and Actuators A, Vol. 121, 2005, 156–161.

[4] A. Fadl, Z. Zhang, M. Faghri, D. Meyer, E. Simmon, “Experimental Investigation of Geometric Effect on Micro Fluidic Diodicity”. Proceedings of the Fifth International Conference on Nanochannels, Microchannels and Minichannels, 2005.

[5] N. C. Tsai, W. Huang, C. Chiang, R. Lee, “Fabrication and Analysis of Valve-less Micro Pumps”. PIERS Proceedings, 2008.

[6] A. Keißner, C. Brücker, “Micro-Flow in a bundle of micro-pillars”. 14th Int Symp. on Applications of Laser Techniques to Fluid Mechanics, 2008.

[7] C. Wang, P. Chang, C. Huang; “Optimization of diffuser valves”. Journal of Marine Science and Technology, Vol. 16, 2008, 134-138.

[8] H. Yang, T. H. Tsai, C. C. Hu, “Portable Valve-less Peristaltic Micropump Design and Fabrication”. DTIP of MEMS and MOEMS, 2008.

[9] W. P. Lan, J. S. Chang, K. C. Wu, Y. C. Shih, “Simulation of valveless micropump and mode analysis”. DTIP of MEMS and MOEMS, 2007.

[10] R. L. Bardell, N. R. Sharma, F. K. Forster, M. A. Afromowitz, R. J. Penney, “Designing High-Performance Micro-Pumps Based On No-Moving-Parts Valves”. Microelectromechanical Systems (MEMS), DSC-Vol. 62/HTD-Vol. 354, ASME 1997, 47-53.