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A novel micropump design: Investigation of the voltage effect on the net flow rate

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Abstract

A low cost piezoelectric micropump was designed and fabricated to supply fluid flow rate in micro-sizes for medical applications. It was designed as disposable in order to prevent contamination and infection. The micropump was fabricated with the Objet260 Connex3 multi-material 3D printer, which was very precise and sensitive. The piezoelectric was selected as an actuator to drive the diaphragm of this micropump. The piezoelectric diameter was 14mm, the thickness was 200 µm and the operating voltages were between 5V-55V. According to the experiments results, the air in the chamber caused reduction of the net flow rate of the micropump. Therefore, we eliminated the air inside the chamber with ethanol before the experiments. In the proposed micropump, we obtained the highest net flow rate and the maximum displacement of diaphragm at 55V that were 40.3ml/min and 2.64µm respectively.

Keywords: micropump design, nozzle/diffuser elements, piezoelectric actuator, COMSOL Multiphysics

1. INTRODUCTION

Health care practices are constantly changing due to the new technologies. These changes improve the quality of diagnosis and patient care. Today, the main requirement of the global community is Micro and Nano-structured technologies. Therefore, in the fields of biology and medicine has been done great challenges. This technology has a potential impact on early diagnosis and treatment of diseases [1-2].

Our main focus in this study was to provide a new method for treating glaucoma. About 57 million people worldwide are affected and this disease is one of the main causes of blindness. Glaucoma is associated with progressive loss of retinal ganglion cells and often arises due to the increased intraocular pressure [3]. The early diagnosis of this disease is very important, because glaucoma can be treated and delay in the treatment of the disease leads to irreversible visual impairment [4]. For treating this disease there are techniques such as eye drops [5], surgery [6], shunt devices [7]. These techniques try to keep intraocular pressure below 21 mmHg. The eye pressure is 8 to 21 mmHg in normal. However, in many cases, eye pressure in this range can be a sign of glaucomatous optic nerve [8].

The shunt device gets implanted into the eye. Unfortunately, some shunt devices cause biological contamination and sometimes, after glaucoma treatment with shunt devices, there is a possibility of an increase in intraocular pressure again. Hence, micropumps can replace shunt devices. Paul Kawun et al. (2016), designed a nozzle/diffuser micropump with an electromagnetic actuator for the purpose of biomedical application, especially treatment of glaucoma disease. The maximum flow rate and the

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maximum back pressure of this micropump in the 12Hz were 135 µl/min and 25 mmH_2O, respectively [9]. Wang et al. (2017) presented a micropump who's its membrane was activated by an external magnetic field. To prevent drug leakage, they used a check valve at the input and output channels. Their goal was to place the micro-pump inside the eye for delivery of the drug [10].

In literatures, there are various actuators for creating vibrations including electrostatic [11], electromagnetic [12], thermal pneumatic [13], shape memory alloy [14], phase change [15] and piezoelectric [16-18]. Piezoelectric compared to other actuators have a fast performance and produce high intermediate pressure in less power consumption which is preferred for biomedical applications [19-20].

This study consists of two main parts. Firstly, we simulated the proposed micropump in the COMSOL Multiphysics 4.3 to calculate the diaphragm displacement and investigated numerically. Secondly, we fabricated the proposed micropump in a clean room by Objet 260 Connex3. This micropump consisted of the chamber, silicon membrane, piezoelectric actuator and two nozzle/diffuser elements. The net flow rates and diaphragm displacements of micropump was calculated at different voltages. The maximum net flow rates and maximum displacements were 40.3ml/min and 2.64µm respectively which obtained at 55V.

2. MATERIALS AND METHODS

Figure 1 shows the micropumps working principle. After we applied sinusoidal voltage to the piezoelectric, it extends and contracts horizontally. Because we have clamped the piezoelectric onto the silicone membrane, the expansion and contraction in the horizontal direction have changed to vertical vibrations. In this case, when the diaphragm bends upwards, the fluid suction takes place from the reservoir into the chamber that is shown clearly in Figure 1. In the second period, the diaphragm bends downwards. In this case, the discharge of fluid take place from the micropump chamber to the outlet channel.

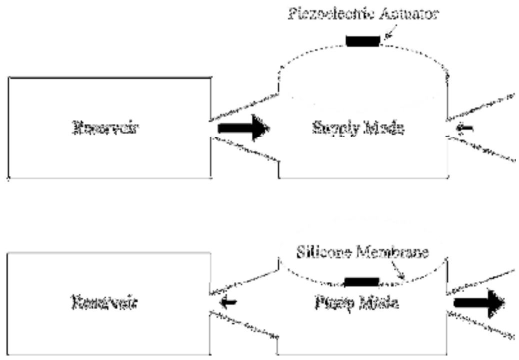

Figure 1. Working principle of the proposed piezoelectric actuated micropump

The channels with a control valve can prevent flow back into the chamber. However, the structure of these channels is complex. There is a possibility of blockage of the valve by small particles or bubbles in liquids [21]. For this reason, we used nozzle/diffuser elements for the micropump's input and output channels. Because these elements don't have moving components and their fabrication process is also easy.

We fabricated the micropump body, nozzle/diffuser and fluid reservoir in a clean room by using the Object260 printer. Object260 Connex3 produced 16-micron layer resolution. Vero Blue RGR840 was used to fabricate these elements.

The upper wall of the chamber was made of silicone rubber membrane with a thickness of 100µm. Piezoelectric actuator with a diameter of 14mm and a thickness of 200µm was clamped onto this membrane. Figure 2 shows the proposed piezoelectric micropump and experimental set-up.

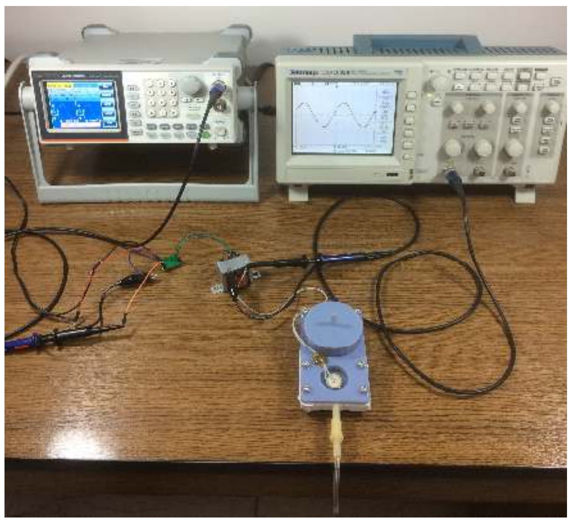

Figure 2. Experimental set-up

The fluid reservoir and the micropump was fabricated in the form of one piece. The reservoir was connected to the micropump chamber by a nozzle/diffuser element. The fluid was injected into the reservoir with a serum hose. Eventually with the vibration of diaphragm, the fluid in the reservoir was transferred to the outlet channel. In this study, water was selected as a fluid. To measure the flow rates, a tube, 4mm in diameter was attached to the outlet. The flow rates can be estimated by measuring the velocity of the fluid in the outlet tube. We recorded the net amount of obtained water of the outlet channel during 1 minute. We repeat this process 10 times for each parameter. In section 3, the results of simulations and experiments were presented and discussed. Finally, the concluding remarks were reviewed in Section 4.

3. RESULTS

3.1. Behavior of diaphragms

In the proposed micropump, the membrane is a key element that has important role in the performance of micropump in drug delivery. To find the optimal micropump design with biomedical applications, we examined the diaphragm behavior. In order to meet the biological needs, we used 5V-55V and 20Hz in our studies.

In simulation, mesh convergence was used to obtain optimal diaphragm displacement values, as shown in Figure 3.

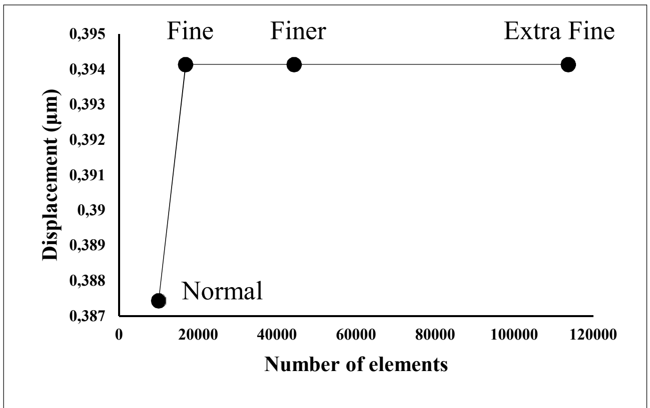

Figure 3. Mesh convergence analysis for central point of diaphragm

In this method, we analyzed the simulated micropump in four steps with four different mesh types. The number of mesh elements increased at each stage. The error rates between the first meshing step (Normal) and the second meshing step (Fine) was 1.66%. Whereas, the simulation results of meshing were equal in the second, third and fourth stages. For this reason, the second meshing step (Fine) with the 16832 element numbers was chosen as the ideal mesh for this simulation. Figure 4 shows the result of diaphragm displacements at different voltages.

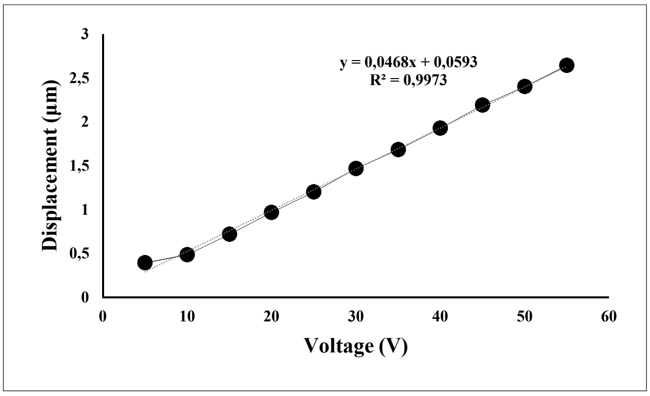

Figure 4. The displacement results at different voltages

Based on the simulation results, maximum displacements occur at the central position of the diaphragm. The maximum displacement accorded in 55V was equal to 2.64µm.

3.2. The net flow rate of novel micropump

The nozzle/diffuser elements do not have mechanical components. The input and the output portions of these channels are always open. Because of this reason, there were some unwanted air bubbles in the micropump's chamber and the air leads to a decrease in the efficiency of the micropump. We filled the micropump chamber with ethyl alcohol, to reduce the amount of air inside the chamber. After evacuation of alcohol, water was used for testing. The performance of presented micropump at various voltage was experimentally investigated. The flow rate increased with increasing in input voltage. The tests were also performed at 20Hz. When the sinusoidal voltage of 55V was given to piezoelectric, the flow rate reached to 40.3 ml/min. We got the lowest flow rate at 5V, which was 8.4ml/min. As shown in Figure 5, the flow rate showed a similar trend of displacements of diaphragm.

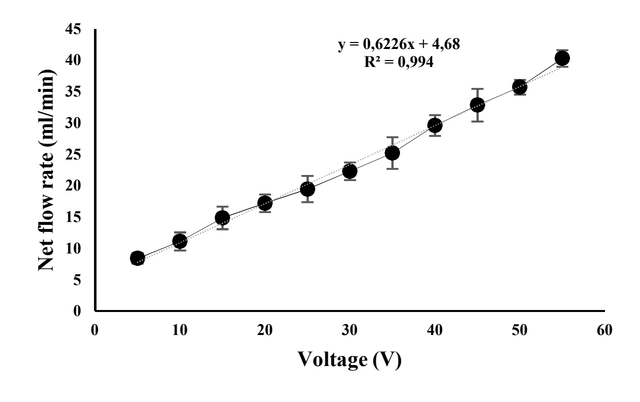

Figure 5. Measured flow rate at different voltages

4. CONCLUSION

In this study, we proposed a micropump which can be actuated by piezoelectric actuator, which might be useful in biomedical applications, especially in the treatment of glaucoma. We studied the effects of voltages on the performance of micropump. The higher voltage created the higher displacement of diaphragm and the higher displacement of the diaphragm also created to a higher flow rate. The maximum flow rate for proposed micropumps was measured at 55V. Therefore, in this study, the ideal voltage was 55V to evacuate the maximum amount of fluid in some eye related health problems such as glaucoma disease. However, the flow rate in this micropump was limited due to its single-diaphragm. Therefore, further studies on multi-diaphragm micropumps are essential. In future studies, we will examine the behavior of multi-diaphragm micropumps.

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