UNIVERSITI PUTRA MALAYSIA

DESIGN AND SIMULATION OF PIEZOELECTRIC MICROPUMP FOR A CONSTANT FLOW RATE

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By

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DESIGN AND SIMULATION OF PIEZOELECTRIC MICROPUMP FOR A CONSTANT FLOWRATE

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A micropump is just like any other ordinary pumps except that it deals with fluids in extremely small dimensions. It works based on the concept of suction and decompression. The challenges faced in designing a piezoelectric micropump are to have a controlled flow rate as well as increasing the efficiency of the pump. The objective of this project is to design a piezoelectric micropump which aims in maintaining a constant consistent flow rate of a liquid of approximately few microlitres per minute by adjusting the voltage and frequency. Different piezoelectric materials were used and their flow rates were studied and PZT proved to be the optimum choice. The projected results display a laminar flow at the required flow rate for the liquid purification system over a period of time. The flow rate of the micropump will be controlled by the voltage and the frequency applied to the piezoelectric layer. The flow rate of this micropump was compared with the theoretical value to study the comparison between the simulated and theoretical results. The simulation for this piezoelectric micropump is done using Intellisuite software. There existed a variation of 7% between the theoretical flow rate and simulated results when a voltage of 20 volts were applied, mean while there existed a variation of 12% when a voltage of 100 volts were applied. This piezoelectric pump is made of PZT (piezoelectric layer), Silicon (Fluid chamber) and Aluminum (Metal contact layer). The flow rate recorded was approximately 0.22 micro liters per second when a voltage of 10 volts were applied at 10 Hz. In conclusion, this piezoelectric micropump was designed for biomedical purposes, hence the requirement of a constant flow rate over a period of time. Shape of diaphragm and channel were designed in order to increase the efficiency of the flow.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK DAN SIMULASI PAM MIKRO UNTUK KADAR ALIRAN MALAR

Oleh

SYED ABDUL BARI

Januari 2016

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Mikropam ialah seperti pam biasa yang lain tetapi ia melibatkan cecair dalam dimensi yang sangat kecil. Ia berfungsi berasaskan konsep sedutan dan penyahmampatan. Cabaran yang dihadapi dalam merekabentuk mikropam piezoelektrik adalah untuk mempunyai kadar aliran yang terkawal serta meningkatkan kecekapan pam. Objektif projek ini adalah untuk merekabentuk satu mikropam piezoelektrik yang bertujuan untuk mengekalkan kadar aliran cecair yang konsisten, dalam anggaran beberapa mikroliter per minit dengan melaraskan voltan dan frekuensi. Bahan piezoelektrik yang berbeza telah digunakan, kadar alirannya telah dikaji dan PZT terbukti sebagai pilihan yang optimum. Keputusan dijangka memaparkan aliran laminar pada kadar aliran yang diperlukan untuk sistem penulenan cecair dalam suatu tempoh masa. Kadar aliran mikropam akan dikawal oleh voltan dan frekuensi yang digunakan pada lapisan piezoelektrik. Kadar aliran mikropam ini telah dibandingkan dengan nilai teori untuk mengkaji perbandingan antara keputusan simulasi dan teori. Simulasi untuk mikropam piezoelektrik dibuat menggunakan perisian Intellisuite. Terdapat variasi 7 % antara kadar aliran teori dan keputusan simulasi apabila voltan 20 volt telah digunakan, manakala variasi 12 % apabila voltan 100 volt digunakan. Pam piezoelektrik ini diperbuat daripada PZT (lapisan piezoelektrik), Silikon (ruang bendalir) dan Aluminium (lapisan logam sentuhan). Kadar aliran yang dicatat adalah kira-kira 0.22 mikroliter per saat apabila voltan 10 volt digunakan pada 10 Hz. Kesimpulannya, mikropam piezoelektri ini telah direkabentuk untuk tujuan bioperubatan, oleh itu keperluan untuk mengekalkan kadar aliran yang tetap bagi satu tempoh masa. Bentuk diafragma dan saluran telah direka untuk meningkatkan kecekapan aliran.

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I certify that a Thesis Examination Committee has met on **22nd January 2016** to conduct the final examination of A.**Syed Abdul Bari** on his thesis entitled **"Design and Simulation of Piezoelectric Micropump for a Constant Flow Rate"** in accordance with the Universities and University Colleges Act 1971 and the Constitution of Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

MEMS	Microelectromechanical System
Vs	Versus
W.r.t	With respect to
W	Energy stored
F	Electrostatic actuation force
V	Voltage applied
x	space between electrodes
ρ	stress on piezoelectric layer
E	Electrical charge
Q	Flow rate
V	Stroke volume
F	Frequency applied
r_p	Radius of piezoelectric layer
X_0	Maximum deformation of piezoelectric layer
r_d	Radius of silicon diaphragm
t_p	Piezoelectric disc thickness
V_p	Voltage over piezoelectric disc
t_{dp}	Ratio of diaphragm thickness to piezoelectric disc thickness
R_e	Reynolds number
Dh	Hydraulic parameter in metres
A	Cross sectional area of channel
V	Average flow velocity
P	Fluid density

CHAPTER 1

INTRODUCTION

The working principle of a micropump can be generally classified into two phases which is supply phase and pump phase. A general diagram of the micropump is shown in Figure 1.1.The supply phase can be defined as the suction phase which is caused due to the pressure being lower in the diaphragm than the channels. The pump phase is the phase where the fluid is pumped out of the central diaphragm due to the pressure being higher in the central diaphragm than the channels.

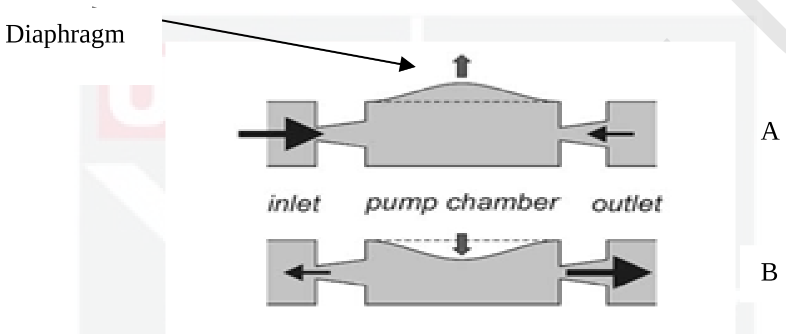

Figure 1.1: Diagram obtained of pump behavior (Nikhil *et al*, 2011).

The presence of valves will avoid unwanted flow of liquid through the micropump thus increasing its efficiency where they act as “fluid rectifiers”. Micropump with valves generally involves the liquid to flow from one chamber to another through valves. The general principle normally consists of the liquid being directed towards the central pumping chamber by opening all the valves leading from the external fluid input valve to the pumping chamber and closing all the valves leading from the pumping chamber to the exit valve. When the chamber is filled with the liquid all the valves leading to the chamber is closed and the valves leading to the exit will be opened resulting in the liquid to be pumped out in only one direction without any backflow. Valveless micro pump works on the principle in which the liquid is brought into the chamber and pumped out due to the displacement of the diaphragm. This causes the liquid to flow in a circular motion (for a circular diaphragm) and the liquid is pumped out through the inlet and the outlet channel.

The choice of micropump in this research has been valveless micropump. This was due to increase the efficiency of the flow as well as to reduce any turbulence present in the flow due to the presence of valves. A constant continuous flow is vital to the application of this micropump.

A flow can be classified into:

1. Linear.
2. Constant.
3. Continuous.

A linear flow process can be defined as a flow which is not turbulent and is smooth flowing. The difference between a constant flow process and a linear flow process is the velocity of the flow. In a constant flow, the velocity of the flow is maintained at a constant value meanwhile in a linear flow process it can vary. A continuous flow can be defined as a flow process without any break or disruption during the flow. Linear and constant flow process can be categorized generally under continuous flow process. This research is being done in producing a constant and continuous flow.

There are different types of micropumps such as Electrostatic micropump, Bimetallic micropump and so on. The different types are explained further in Chapter 2. One such type is piezoelectric pumps which is one of the more commonly used micropump due to its various applications. Piezoelectric pump enables precise control of fluid flow by controlling the voltage applied to the piezoelectric material. The piezoelectric material used in this model is PZT (Lead Zirconate Titanate) and Si is used for building the diaphragm which is suitable for fabrication process. Some of the other materials used commonly as the piezoelectric materials are SiO_2, ZnO. PZT and SiO_2 are prominently used for piezoelectric actuation. The choice of material for electrodes is Aluminum.

This reason behind the choice of research, constant flow process is its use in the field of medicine and pharmaceutical purposes. The need of a constant flow especially in production of various drugs will be mentioned in the literature review.

1.1 Problem statement

The use of micropumps in various fields is rising due to its various advantages such as its small structure. Designing a micropump with a constant and continuous flow will be one of the most important considerations, which will be deliberated further in this research. Literature reviews of other micropumps designed by Lee (Lee *et al.,* 2004) and Anders (Anders *et al.,* 1997) concentrate on trying to obtain the maximum flow rate rather than controlling of the liquid flow. This is very important as one of the major application of this micropump i.e. injecting insulin for patients experiencing Diabetes (Chou *et al.,* 2006) or for a water purification system.

The most common problems present in the designing of a piezoelectric micropump are:

1. Constant continuous flow rate: For biomedical purposes especially in the field of drug delivery system, the flow rate should be maintained at a particular flow rate for a long time. Being able to control the flow rate proves to a specific value proves to be a huge advantage. There are many reasons behind a flow process not being constant and continuous such as losses due to eddy currents and turbulence due to shape of the diaphragm of the piezoelectric pump.
2. Resonant frequency: In any piezoelectric pump, the resonant frequency varies based on the piezoelectric material used. Determining this will allow the flow of the piezoelectric pump to be constant and continuous.

1.2 Objectives

Due to the problems mentioned in the previous section, the objectives of this research are as below:

1. To determine the effective parameters of micropump for a constant and continuous flow rate.
2. To evaluate the performance of the designed micropump.
3. To compare the simulation results with that of the theoretical modeling.

1.3 Scope of Research.

This research is based on designing a micropump for a specific purpose such as for miniature analytical / diagnostic or prognostic device. The stability of the flow and maintaining the flow rate is given utmost importance. Some of the limitations are as follows:

1. Frequency: This micropump works in a specific frequency where its efficiency is maximum. Varying the frequency (1Hz-100 Hz) can cause a lot of distortion in the flow behavior. This range (1 Hz- 100 Hz) was selected based on literature study of other micropumps used for medical and biological processes (Lee *et al*, 2004) (Doll *et al*, 2005) which have been discussed in Chapter 2.
2. Choice of material: When the piezoelectric material is varied between Silicon dioxide and PZT which are used for piezoelectric micropump for their inert nature as well as their ability to be biocompatible (Cui *et al*, 2008 and Ashraf *et al*, 2011) which have been discussed in Chapter 2.
3. A comparison of the simulation result and the theoretical calculation is done to verify the simulation result using Intellisuite software.

1.4 Layout of thesis

This thesis consists of five sections. The first, being the introduction, which gives a brief description on the concept of micropump and its various types. It also defines on the objective and scope of work for this thesis.

This chapter is followed by the literature review which provides a study on the various works done by other researchers in this area of study. This allows better understanding on the development of this area of work and also allows us to comparatively study their work.

The third chapter consists of the methodology used in this thesis for this research. The various design parameters and the calculations are elaborated here.

The fourth chapter displays all the results obtained from this simulation and the review on the obtained results is discussed. These results allow studying the efficiency and other parameters which have an effect on a piezoelectric micropump.

The final chapter summarizes the various findings in this research and provides a general and concise summary of this research.

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