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DISTINCTIVE ANALYSIS OF FLUID FLOW BEHAVIOR OF AC ELECTROOSMOTIC MICROPUMP

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DISTINCTIVE ANALYSIS OF FLUID FLOW BEHAVIOR OF AC ELECTROOSMOTIC MICROPUMP

By

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Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
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DISTINCTIVE ANALYSIS OF FLUID FLOW BEHAVIOR OF AC ELECTROOSMOTIC MICROPUMP

By

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The fluid flow behavior in an alternating current (AC) electroosmotic micropumping device has been studied experimentally and theoretically using an electrohydrodynamic theoretical model applied to a computer simulation model. It has been analyzed using two different theoretical approaches; first is "Ramos slip velocity" and the second, "Coupled ACEO numerical" model. This micropump is using a coplanar microelectrode array that engages the principle of AC electroosmosis (EO), ion driven in the direction of surfaces due to Coulomb forces by tangential electric fields. These ions, when activated, produce a net movement of fluid flows caused by viscous drag forces. The result of AC electric field to an electrolyte using coplanar microelectrodes creating a travelling wave of potential and has given steady fluid flow across the microelectrode array. The flow has its origin in the interaction of the tangential component of the nonuniform field with the induced charge in the electrical double layer on the electrode surfaces.

The velocity that experimentally measured was from movies collected by researcher at Southampton University in United Kingdom. Two micrometer size of particles were suspended in potassium chloride (KCl) with conductivity 14.5 µS/m was used as an aid of visualization in order to measure the fluid velocity when the device work as pump. The experimental results were reviewed for different range of voltages (2 Vpp- 20 Vpp) and frequencies (10 kHz -10 MHz). Maximum velocity was achieved at an AC signal frequency of 90 kHz in 16 Vpp approximately 3.1×10^{-1} µm/s. They were in good agreement with the theoretical predictions, produced using the computer simulation model with MATLAB and COMSOL.

Overall, the bulk fluid flow driven by this surface is numerically calculated as a function of voltage and frequency. It shows a good agreement between the numerical and experimental streamline and comparable to previously computer simulation framework to analyze future micropump design concepts.

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

ANALISIS TERSENDIRI GELAGAT ALIRAN BENDALIR OF MIKRO ELEKTROOSMOTIK AU

Oleh

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Perilaku aliran bendalir dalam arus ulang-alik (AU) peranti pam mikro elektroosmotik telah dikaji secara eksperimen dan teori dengan menggunakan model teori elektrohidrodinamik yang digunakan untuk model simulasi. Ia telah dianalisis dengan menggunakan dua pendekatan teori yang berbeza, pertama adalah "halaju tergelincir Ramos" dan kedua, model "gandingan berangka ACEO". Pam mikro ini menggunakan pelbagai elektrod sesatah yang melibatkan prinsip elektroosmosis AU (EO), di mana ion didorong ke arah permukaan yang disebabkan oleh daya Coulomb teraruh oleh tangen medan elektrik. Apabila diaktifkan ion-ion ini, ia akan menghasilkan pergerakan bersih aliran cecair disebabkan oleh daya-daya seretan likat. Hasil medan elektrik AU kepada elektrolit yang menggunakan elektrod mikro sesatah mewujudkan keupayaan gelombang pergerakan yang telah memberikan aliran bendalir yang mantap di seluruh elektrod

mikro itu. Aliran ini mempunyai asal mula dalam interaksi komponen tangen medan cas tak seragam dengan muatan teraruh disebabkan terdapat lapisan elektrik berganda pada permukaan elektrod.

Halaju yang diukur adalah hasil dari eksperimen adalah daripada filem yang dikumpul oleh penyelidik di Universiti Southampton di United Kingdom. Zarah bersaiz dua mikrometer diletakkan didalam kalium klorida (KCl) dengan kekonduksian 14.5 μS / m telah digunakan sebagai bantuan visual untuk mengukur halaju bendalir apabila peranti bekerja sebagai alat pam. Keputusan eksperimen telah dikaji semula untuk pelbagai jenis voltan (2 Vpp-20 Vpp) dan kekerapan (10 kHz -10 MHz). Halaju maksimum dicapai pada isyarat frekuensi 90 kHz AU dalam 16 Vpp kira-kira 3.1×10^{-1} μm / s. Dengan keputusan yang dihasilkan ini maka ianya berada dalam perjanjian yang baik dengan ramalan teori yang menggunakan model simulasi komputer MATLAB dan COMSOL.

Secara keseluruhannya, sebahagian besar aliran bendalir yang didorong oleh permukaan ini dikira secara berangka sebagai fungsi voltan dan kekerapan. Ia menunjukkan satu perjanjian yang baik diantara angka dan eksperimen yang selaras dan setanding dengan rangka kerja simulasi komputer sebelum ini untuk menganalisa konsep rekabentuk pam mikro masa depan.

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

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for other degree at Universiti Putra Malaysia or at any other institution.

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Date: 5th February 2013

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LIST OF ABBREVIATIONS

µTAS	Micro Total Analysis Systems
LoC	Lab-on-a-Chip
POCT	Point of Care Testing Systems
EOF	Electroosmotic Flow
SMA	Shape Memory Alloy
KCL	Potassium Chloride
ICPF	Ion Conductive Polymer Film
EHD	Electro Hydrodynamic
EW	Electro Wetting
EDL	Electric Double Layer
AECO	Alternating Current Electro-Osmotic

CHAPTER 1

INTRODUCTION

1.1 Background

When studying a class of devices it is always useful to have a good understanding of potential target applications. In the case of microfluidic systems, common target applications include chemical and biological analyses, biological and chemical sensing, drug delivery, molecular separation, amplification, sequencing and synthesis for environmental monitoring. A microfluidic system is one where fluid flows in miniature devices. It makes biological assays more effective through reduced reagent quantities and shorter reaction time. It is relatively inexpensive and can be integrated with other functional miniaturized components. It can contribute to the precision control systems of industries such as automotive, aerospace and machine tools. Most microfluidic systems have two or three-dimensional microchannels through which fluid samples are pumped (often concurrently and in various mechanisms), controlled and manipulated [1].

Most microfluidic systems need a self-contained active pump of a size comparable with the volume of fluid to be pumped. The key considerations for them include their reliability, power consumption, actuation voltage, ease and cost of fabrication, biocompatibility and a dosing accuracy comparable with that of a fuel pump [2]. A typical micropump is a MEMS device; it is the actuation source through which a fluid sample (drugs and therapeutic agents) is transferred with precision, accuracy and reliability from a reservoir to the target [3]. Typical applications include drug delivery and biomedical pharmaceutical, environmental monitoring and even homeland security applications such as Micro Total Analysis Systems (μTAS) or Lab-on-a-Chip (LoC) and Point of Care Testing Systems (POCT); reliability and robustness of the micropump are thus essential [4]. In such diagnostic systems, integration and miniaturization are achieved by combining them on a single chip or package, if MEMS micropumps, biosensors and a controlled drug delivery system. The controller can precisely calculated and released an optimal amount of drug at an optimal time through the microactuator. The controlled drug release includes localized and precise site-specific drug delivery. It has many potential benefits besides reducing side effects (e.g. fluctuating levels of the circulating drug) and increasing therapeutic effectiveness [5].

Development of micropumps that was usable in single or two-phase cooling of microelectronic devices has been a challenge because in microelectronics cooling the flow-rate requirement is highly demanding [6]. Recent developments in miniaturization of these systems have enabled their application to chemical and biological analyses. An obvious advantage of miniaturization besides if reduce the form factor of the systems when applied to micro total analysis system, is the yield of reduce improvement to performance (e.g. faster completion of assays) and cost reduced (e.g. through fewer manual interventions, decreased in amount of samples and reagents used, cost of fabrication cost and the use of disposable substrates [7]. Miniaturization also aids in system transportation which can give lots of advantageous to some applications [8]. Space exploration can also benefit from micropump technologies. Transportation of miniature roughing pumps for mass spectrometer systems, for example, meets the lightweight requirement of spacecraft [9].

The first real MEMS micropumps were fabricated by using conventional technique. Only in 1984 a micropump based on silicon microfabrication technologies had begun and this has attracting interest, when the size can be reduced and when fully functional pump can be created. The results were published by Smits in 1990. It was a peristaltic pump with three active valves actuated by piezoelectric discs. It was developed primarily for pre-measured insulin delivery in automatic systems that maintain diabetic patients' blood sugar levels [10].

In 1988 Van Lintel at al. had presented the first micropump that has passive check valves. Theirs was the first attempted at fabricating on a silicon that functioned on piezoelectric actuation. It was still a three-layer set-up - two glass sheets enclosing an anisotropically etched silicon wafer [11].

The past 10 years have seen various pumps introduced (whether with moving or non-moving parts) and scaled down, and many papers on micropump invention have been published. Some review articles commented on those invention, particularly concerning mechanical part of the micropumps [12].

The membrane of a mechanical micropump can be actuated whether by piezoelectrically, pneumatically, electrostatically, or electromagnetically. All the membrane types would allow pumping of almost any kind of liquid. Their typical flow rate is 1±100 ml/min. The membrane actuation mechanism is the one that affects the flow [13].

Non-mechanical micropumps have no moving parts; they can create a free-flow pulse. Their fluid driving force can be magnetic, thermal, chemical (as in osmotic pumps), acoustical, or electrical actuation. Electrohydrodynamic pumps can pump dielectric liquids, whereas the air bubbles produced through electrolysis in electrochemical pumps expulse the solution from a close reaction chamber, and electrokinetic pumps are driven by the effect of electroosmosis and electrophoresis [14].

1.2 Motivation and Problem statement

More than 10 years of significant research have been invested on developing chip-based capillary electrophoresis systems with electroosmotic flow (EOF) pumping mechanism. Some of those were pioneering. Those systems have the voltage applied across the length of the solution conduit. Creating high pressure in the small capillaries is also possible, unlike in Newtonian systems [15]. Despite those features, EOF still has one important limit of practicality. The composition of the pumping fluid affects EOF characteristics. A very high or very low pH of the carrier solution, a highly conductive saline, or a non-conducting organic medium will result in the current levels being either excessive or inadequate to support significant EOF [16].

In this project the ACEO micropump was chosen as pumping mechanism because of the above mentioned advantages, and also because the technology required building such electroosmotic pumps and their associated microfluidic components is uncomplicated. Moreover, at the moment, modeling and simulation on low power micropump are not very extensively discussed in papers or in the research especially with MATLAB software.

1.3 Research aim and Objectives

The objectives for this project are to analyze fluid flow of ACEO micropump using an electrolyte fluid medium to measure velocity and to compare the experimental results to the theoretical results produced with the theoretical model in MATLAB software and to extend study on modeling and simulation of low power ACEO micropump in Comsol Multiphysics 4.3a software. It was hoped that the numerical model could be used or improved for evaluating future design concepts to estimate their performance practically before committing to fabricate a device. The objectives for this project are; a) To analyze experimental fluid flow velocity profile using Vision Assistant (VA) and Labview program and mathematical calculation.b) To simulate and model the fluid flow velocity profile using the appropriate model(mATLAB and Comsol Multiphysics 4.3a.
c) To compare results from model and experimental results.

1.4 Method statement

One of the key challenges and important aspect of this thesis is the measurement of the velocity of the ACEO micropump. The theoretical analysis of the microfluidic device was reported can be completed using the finite element method [17]. Therefore the method of this project was to apply a previously developed theoretical model [18] to extract as much information as possible from analysis results because an improved understanding of theoretical ACEO models would aide in the assessment of future ACEO microfluidic array design concepts.

The initial approach was to fabricate the micropump with the required dimensions in glass, but unfortunately there was no available equipment in the laboratory that was suitable for the fabrication of this type of micropump. The best available alternative to measure the velocity is an experimental data that was collected by researcher at Southampton University in United Kingdom. The experimental work was captured and documented in a movie that shows the fluid flow consist of two micrometer particles in potassium chloride (KCl) in a glass substrate , but the results and velocity measurements have never been analyzed which I intend to do as part of my research work. A very precise equipment was used to prepare this movie, including high precision microscope to perform the measurements.

1.5 Thesis arrangement

The thesis is organized as follows: Chapter 2 will present classification of micropumps, evaluation of micropumping technologies and the theory required to understand ACEO. Chapter 3 presents MEMS technology and fabrication method used for electroosmotic pumps. Chapter 4 presents the theoretical model used and how it was applied to the MATLAB software to generate the numerical results. For the experimental, the measurement of the velocity of the ACEO micropump with the specific dimensions has been focused. Chapter 5 consists of a discussion and future work and recommendation Finally the conclusions reached in this project is summarized.

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