Experimental Investigation on the Effect of Micro Cavity - Micro Channel Angle on the Reciprocating Motion of Mercury in a Micro Cavity

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Abstract**—**The benefits of using electromagnetic force in micro-pumps led to produce Magneto Hydro Dynamic micro-pumps. The function of these micro-pumps is based on the magnetic force which is applied to the mass of mercury existent in micro cavities connected to the micro-channel.

This research experiments on the role of outlet micro cavity angle in the amount of mercury entering into the micro-channel. This experiment was conducted by photographing diverse angle positions and analyzing the results with the aim of finding the most efficient angle.

Keywords**—** Electromagnetic force, Mercury, Micro cavity Micro-channel

I. Introduction

AT the beginning of the 1980 decade, in his initial plans, Smith was seeking a micro-pump with the intention of injecting insulin and balancing the blood sugar in diabetics without repetitive syringe injections. [1]

Nowadays expressions such as "Micro total analytical systems (μTAS)" or "Lab-on-a-chip (LOC)" are well known among researchers.

In general, the goal of these systems is displacement, reaction, severance and identifying the samples in an instrument the same size of a chip. Therefore it leads to less sample use, reduced analysis time and easier transportation. Minute fluid displacement for reactions and chemical analysis has affected the laboratory technology on chips and has led to extensive researches. [2]

Although different mechanisms with diverse stimuli have been used in micro-pumps, but integration of micro-pump and other components in order to create a laboratory on a chip is not accessible yet. Due to the existing restrictions, Usage of micro-pumps has not been popular yet. These limitations include lack of effective function and ways to combine or connect micro-pumps with other system components.

Various designs for diaphragm micro-pumps have been offered. Overall, micro-pumps can be classified into two categories, dynamic and reciprocal.

Micro-pumps can be stimulated in different ways such as piezoelectric [3], electrostatic [4], thermal [5] and pneumatic [6]. Pulsed flow and air bubbles restrict the diaphragm micro-pumps. High voltage is needed for piezoelectric and electrostatic stimuli. Thermal stimulus may result in fluid biological decomposition and change in protein structure. Besides, diaphragm type requires valves for flow guidance. Thus possibilities of particle trapping exist.

In dynamic micro-pumps, energy is continuously transferred to the fluid. The required force to achieve pressure difference can be gained by various methods such as Magneto Hydro Dynamic (MHD), Electro Hydro Dynamic (EHD) and Electro Osmotic Pump (EOP) which are respectively motivated by magneto dynamic volume force, electrostatic volume force and forcing the ions on the surface.

Stimulating the mercury micro cavity connected to micro-channels by electromagnetic force in fixed pattern will pump the fluid in electromagnetic mercury micro-pumps. [7]

This study examines one of the effective parameters of micro-pumps functioning, the angle which mercury micro cavity is connected to micro-channel. The experiment methods, equipment and results are given.

II. Design of Experiment

In order to create equal conditions for all the tests, all the micro cavities were designed on a micro-channel with the outlet angle of 50 to 120 degrees. (10 degrees apart)

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Due to the purpose of understanding the effect of mercury micro cavity angle with micro-channel on the micro-pump performance, volume of the liquid in the micro cavity, electric power into mercury, magnetic field and force frequency on mercury were kept constant. Thus the only parameter was the angle between the micro cavity and micro-channel.

To measure the effect of this parameter, electrical field was forced into a micro-pump positioned in a magnetic field and photographs were taken to quantify the amount of mercury entering the micro-channel.

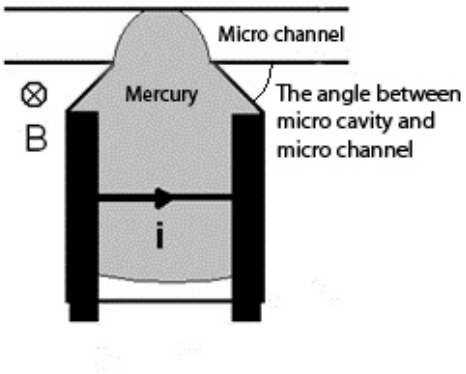

Fig. 1 Schematic view of the micro cavity – micro channel angle

It was predicted that by increasing the collision angle, the amount of mercury entering the micro-channel increases. However, when the collision anger passes a specific limit, mercury drops leave the micro cavity and spread in the micro-channel, hence the air passage will be closed.

III. Instrumentation

A. Electronic Instruments

In order to declare the mass of the mercury to stimulate, it is required to design a system which is able to create the desired pattern and deliver it to the mass of mercury in the form of an electrical current. This system has two parts: a computer program and an electrical board which converts the computer output to electrical current. The computer program was developed using Lab VIEW[1]. In the final design of the electrical board, PCI-1711L-BE data card - a production of Advan Tech Company - was used. Since this card is installed on the computer motherboard, it is necessary to have an extension cable and an electrical board to get the desired output. PCI-1711 series are one of the multifunction cards for PCI Bus. Their advanced circuit design offers high quality and performance. Specifications related to digital output device which is used in this project, can be seen in Table I.

In order to use the output of data generating device, an industrial wiring terminal board with CJC[2] circuit is used. This board should be appropriate for the selected data generating device; so the PCLD-8710 model - a production of Advan Tech Company - was selected. This board is connected to the main board using a PCL-10168 with a length of one meter. The electrical pulse coming from the data generating card should be sent to the micro-pump in the form of electrical current. So the board was used to perform such work for four independent channels. In this project it was desired to produce positive and negative currents when receiving electrical pulse. In fact, by receiving the electrical pulse, the desired board should be able to reverse the direction of electric current. This board can handle a maximum of 5mA for all channels. The delay in production of current is less than 1ms for this board.

TABLE I
DIGITAL OUTPUT OF THE DATA GENERATING CARD

Number of Input Ports	16	
Input Voltage	Minimum	0.8 V
	Maximum	2.0 V
Number of Output Ports	16	
Output Voltage	Minimum	0.8 V at 8.0 mA (sink)
	Maximum	2.0 V at -4.0 mA (source)

B. Design and fabrication of micro-pump body

In this project, an innovative method was used to create the micro channel and micro cavity. Initially the micro channel was created by this method and then a new innovative approach has been suggested to solve the problem of sealing the channel which more will be explained.

A 3mm thick sheet of Plexiglas was used for the body of micro cavity and a 1mm thick sheet was used for the cover of micro channel and micro cavity. Plexiglas is actually a type of transparent thermoplastic which is known with the scientific name PMMA. General characteristics of this material are given in Table II.

TABLE II
GENERAL CHARACTRISTICS OF PMMA

Chemical Formula	Density	Melting Point	Boiling Point
$(C_5H_8O_2)_n$	1.18 $g.cm^{-3}$	160 °C	200 °C

For cutting and engraving desired designs on sheets of Plexiglas, laser cutting machine with the characteristics shown in Table III was used.

TABLE III
CHARACTRISTICS OF THE LASER CUTTING MACHINE

The power of Laser	80-90
Working table area	160×100 cm
Type of Laser	tube CO_2
Engraving speed	0-50 m/min
Cutting speed	0-20 m/min
Supported software	AutoCAD – Corel Draw

While engraving on Plexiglas Sheets, the engraving depth and elegance of design depends on three parameters:

[1] Laboratory Virtual Instrument Engineering Workbench
[2] Cold Junction Compensation

1) The power of Laser
2) The speed of moving element on workpiece (Laser speed)
3) The displacing accuracy of the moving element (The time interval between each cycle, The gap)

After creating the desired depth and width for the desired channel, putting a cap on channel and micro cavity and sealing them has a great importance. Since the material which is used for the cap on channel and micro cavity is the same as one in the body, the first and easiest way forward is using the chloroform solution which is a suitable solvent for Plexiglas sheets. This solution is used in most industrial applications in which two sheets of Plexiglas should be firmly and permanently attached to each other. It is commonly named as Plexiglas glue. In this project, for attaching the cap to micro-pump body, a chloroform solution was used. This must be done with very high accuracy. Since the channel is narrow and shallow, if the adhesive which is injected into the space between two Plexiglas sheets is a little too much, the glue will get into the channel and cause it to be stuffy. On the other hand, excessive caution and inadequate injection of glue may cause the fluid to penetrate to the space between two Plexiglas sheets and interfere with the experiment when it is flowing through the channel.

IV. Result and Discussion

According to the results of imaging, it is observed that in small micro cavity-micro channel angles the amount of mercury coming out of the micro cavity is very low. This phenomenon can be explained by the surface tension of mercury. In small angles, the micro cavity-micro channel angle is smaller than mercury contact angle; therefore, a discontinuity in the mass of mercury is required for the entry of mercury into the micro channel. So, due to the constant applied force, a small amount of mercury will enter the micro channel.

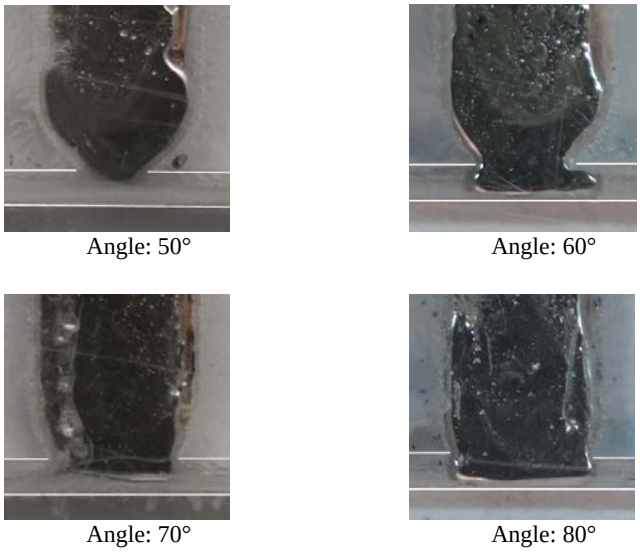

Fig. 2 Pictures taken from the mass of mercury for angles between 50° to 80°

An increase in the micro cavity-micro channel angle will cause the mass of mercury to enter the micro channel more easily. But in angles larger than 80°, the mass of mercury will be less exposed to the opening of micro cavity. Consequently, due to the mercury adhesion with micro channel, the possibility of separation in the mass of mercury rises. As a result, we observe the distribution of mercury within the micro channel and closure of the fluid flow path.

Fig. 3 Picture taken from the mass of mercury for angles more than 80° (Angle: 100°)

V. Conclusion

The performance of mercury stimulated micro-pumps with electromagnetic stimulation improves by increasing the collision angle between micro cavity and micro-channel up to 80 degrees. But with further increase, mercury drops spread in the micro-channel. Therefore the best performance angle between the micro cavity and the micro-channel is 80 degrees.

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