Faculty of Engineering

Micro-Needle Integrated with Micro-Pump for Drug and Blood Deliveries in Polygonal Inner Structures of Micro-Channels

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DECLARATION

I, Yana Shaheera binti Yunos (15020312), Faculty of Engineering hereby declare that the work entitled Micro-Needle Integrated with Micro-Pump for Drug and Blood Deliveries in Polygonal Inner Structures of Micro-Channels is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

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Signature

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Date : 15 June 2020

DEDICATION

Specially dedicated to

My beloved parents, Yunos bin Aili and Suriany binti Mohd Yusof, and the only sibling I have, Yazeed Shazeril who have encouraged and keep supporting me through the journey in master's education.

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ABSTRACT

Blood is a complex suspension that demonstrates non-Newtonian rheological characteristics. The study of hemorheology has been of great interest in the fields of biomedical engineering and medical researches for many years. Micro-channel such as micro-needle has been an expanding medical technology in recent years due to their ability to penetrate tissue and deliver therapy with minimal invasiveness and patient discomfort. Micro-channel geometries have been used to study the inertial insertion focusing on behaviour of particles suspended as variations in design. The studies have enhanced fluid delivery in biomedical field. This research presents a comparison on dynamic characteristics of flow velocity and pressure losses in micro-needle using numerical and experimental analysis. The advancement of research is also conducted by integrating the micro-needles with micro-pump to improve their functions during fluid deliveries. The micro-needles with channel inner design of circle, square, hexagon and dodecagon came with various design parameters. These geometry studies had improved the flow performance and the efficiencies in delivering drug and blood using polygonal structured micro-needles.

Keywords: Micro-needle, micro-pump, polygonal, fluid delivery

Jarum Mikro Bersepadu dengan Pam Mikro untuk Penghantaran Dadah dan Darah dalam Saluran Mikro Berstrukturkan Poligon

ABSTRAK

Darah adalah satu unsur yang kompleks untuk menunjukkan karakter-karakter bukan Newtonian. Pembelajaran tentang reologi darah telah memberi impak yang besar dalam kejuruteraan bioperubatan bertahun lamanya. Salah satu contoh saluran mikro yang telah lama berkembang dalam bidang teknologi perubatan adalah jarum mikro yang faktor utamanya adalah mampu menembusi tisu-tisu dan menghantar terapi dengan kesakitan yang minimum dan mengurangkan ketidakselesaan pesakit. Geometri saluran mikro telah lama digunakan untuk mengkaji perilaku dalaman zarah yang mengalir dalam variasi rekabentuk. Pembelajaran ini telah meningkatkan penghantaran cecair dalam bidang bioperubatan. Penyelidikan ini mengemukakan perbandingan di antara ciri-ciri dinamik terhadap halaju pengaliran dan kehilangan tekanan dalam saluran mikro menggunakan analisis berangka dan eksperimen. Kemajuan di dalam penyelidikan ini juga dikendalikan dengan menyepadukan jarum mikro dengan pam mikro untuk meningkatkan lagi fungsi semasa penghantaran cecair. Jarum mikro dengan saluran dalaman berbentuk bulat, empat segi, heksagon dan dodekagon, didatangkan dengan reka bentuk parameter yang lain. Pembelajaran geometri ini telah meningkatkan prestasi halaju dan keberkesanan dalam penghantaran ubat cecair dan darah dengan menggunakan jarum mikro dengan berstrukturkan poligon.

Kata kunci: *Jarum mikro, pam mikro, poligon, penghantaran cecair*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternate Current
cm	Centimeter
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
E_L	Energy Losses in Micro-needle
g	Gravitational force
k-ε	k-epsilon
MEMS	Micro-Electro Mechanical System
mm	Millimeter
NC	Numerical Control
Pro-E	Pro-Engineering
ρ	Density of Fluid
SEM	Scanning Electron Microscope
v	Velocity of Fluid Delivery
wt %	Weightage Percentage
y	Elevation of fluid flow
μm	Micrometer
η	Dynamic Viscosity of Blood
$Ø$	Diameter of Micro-needle

CHAPTER 1

INTRODUCTION / LITERATURE REVIEW

1.1 Background of Research

Injecting drug and blood withdrawing techniques are obtained either from arteries or veins. Using hypodermic needle to penetrate human skin until it reaches the arteries or veins is surely uncomfortable and painful. From the beginning of the realization of painless needle from mosquito's mechanism of blood withdrawal, lots of research has been conducted to improve the efficiency of the micro-needles for drug delivery and blood withdrawal from various sizes of needle and designs. From hypodermic needles to the current conventional micro-needle, the advancement of the researches leads to the technologies of micro-needles. This technology is aimed at improving the flow and performance while completing the task of penetrating the human outermost skin to withdraw blood or injecting drugs into the living organisms' vessels (Khumpuang et al., 2007).

1.2 Problem Statement

The manufacturing of micro-needle is recognized in medical field for diabetic patients, but because of their limitations to deliver large amount of liquid, their usage is restricted to infuse insulin only. Micro-needle patches are bound for small volume of insulin delivery into human skin and are convenient for patients as they must take regularly the insulin.

Due to the limitations of volume delivered, the micro-needle needs to be improved in length and diameter, so it can be attached to the syringe and deliver certain volume of drug and blood straight into the blood stream. Conventional micro-needle only passes the human skin barrier, stratum corneum for the drug to be diffused into human body. This is also the reason why the micro-needle needs to increase the length so that blood and other drug which contains more molecules inserted into the vessels, while keeping the velocity constant during the delivery.

Increasing the length of micro-needle is a better option to deliver it direct to vessel and attaching micro-pump can increase velocity of the fluid. Thus, a larger volume of fluid can be delivered while keeping micro-needle in micron size.

1.3 Aims of Research

This research would be able to assist the practicing engineer to increase and improve the design of micro-needle integrated to a micro-pump to achieve better flow performance in drug and blood delivery into human body effectively and efficiently. Thus, by doing so, our medical industry on designing and manufacturing medical appliances can be improved.

1.4 Objectives

The objectives of the study are:

i. to evaluate and predict average velocity in micro-needle when micro-pump is attached

ii. to investigate and compare the flow pattern in both numerical and experimental results

iii. to improve flow dynamic and static characteristics of drug and blood delivery

iv. to evaluate the energy losses in micro-channels during delivery

v. to investigate and compare the inverse area dynamic profiles in micro needles during delivery

1.5 Scope of Research

To comply with the objectives, there are several considerations and constraints that need to be considered. They are:

i. using human blood is prohibited in experiments

ii. velocity inlet for drug delivery is based on calculation using the Bernoulli's equation

iii. velocity inlet for blood delivery is based on laminar inflow of blood flow

iv. micro-pump's diaphragm movement is converted from the specification of lowest and highest micro-pump flow rate value.

1.6 Micro-needle Developments

1.6.1 Anatomy of Mosquito's Fascicle

Only female mosquitos feed on human blood to obtain the protein needed for their eggs production. They feed via a tubular component of their mouth which is called proboscis. The proboscis itself consists of labium and fascicle. Labium acts as protective sheath while

the fascicle, which is mandibles (thin tube), maxilla with tooth of saw tips and flat hypo-pharynx with a central salivary duct, provides a primary path that channels the blood flow (Jones, 1978). The fascicle of *Aedes Aegypti* is commonly 1.8 mm long and 11 μm in internal radius (Daniel et al., 1983). The itching effect produced after biting human skin is due to the allergic reaction of the mosquito's saliva as they secrete during the blood sucking process to prevent the platelet to aggregate (Ribeiro et al., 1984). Figure 1.1 shows a SEM (Scanning Electron Microscope) picture of mosquito's proboscis (Swaminathan, 2006).

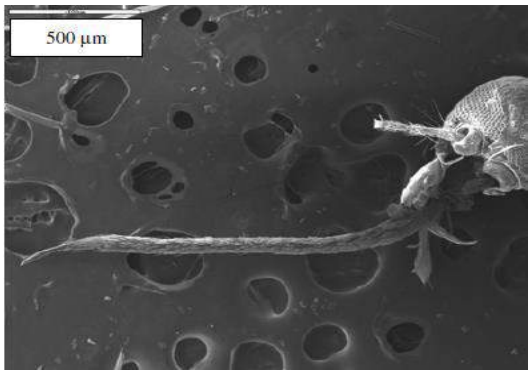

Figure 1.1: Mosquito's proboscis (Swaminathan, 2006)

Once mosquito landed on its host, they start thrusting their proboscis onto the human skin. To find suitable spot so that the proboscis can penetrate the skin without bending, they probe other spot as the fascicle tip anchors down the outermost layer of skin (Ramasubramaniam et al., 2008). The tip of the fascicle is very sharp that it is claimed to taper from 10 μm to less than 1 μm over the last 50 μm of the fascicle and the v-shaped of the tip ridged near the tip almost to 50 μm in length (Wick et al., 1984).

The basic of developing and designing a painless needle will be based on the typical hypodermic needle's tip used and mosquito's fascicle tip shape. The mosquito