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Analysis of Pressure and Velocity Variation in T-shaped Channel at Micron Level

Faiz-Ul-Hassan[1], Tariq Bashir[*,1] and Shaista Jabeen[1]

[1]Electrical Engineering Department, COMSATS University, Islamabad, Pakistan
*Corresponding author: Tariq Bashir (e-mail: tariq_bashir@comsats.edu.pk).

Abstract- **Micro-electromechanical systems (MEMS) are microscopic devices based technology mainly involving the moving parts. Bio-MEM is a particular affiliate of MEMS technology in general. This paper studies and analyzes variations of pressure and velocity inside the T-shaped channel at micron level. We have considered straight micro-channel for multi-field analysis among different types of micro-channels, i.e., sinusoidal, curved, straight, spiral and snake fang. The surface (inlet, outlet and walls) is defined for channel while water at 25C is to be assumed as working fluid. Moreover, parameters including diameter and length of channel are defined as well as meshing has been performed in 3-D formation. The fluid dynamics including pressure and velocity variation inside the channel are visualized using ANSYS CFX-solver.**

Index Terms-- **ANSYS, Fluid Flow, MEMS, Micro-channel.**

I. INTRODUCTION

Micro-fluidic devices using MEMS technology have become much popular in the last decades in the field of biomedicine. Motion of fluid flow is primarily considered in micro-fluidic systems [1]. Manipulation mechanisms including mixers, filters and valves are mainly based on micro-fluidics and their implementation is the main goal for scientists and researchers [2]. Micro-fluidic devices generally involve; (i) micro-needle (ii) micro-pump (iii) micro-mixer and (iv) micro-channel. Some applications of the MEMS include; inkjet printers, accelerometers, displays devices, drug delivery, blood extraction, microsurgical tools, optical switching, fluid acceleration, mechanical, gas and chemical sensors, fuel cells, inter-ferometric modulator display, biomedical transducers, micro-scale based energy harvesting via piezoelectric and MEMS based gyroscope inside modern vehicles [3, 4]. According to the Technavio report, market segmentation of Bio-MEMS and the micro-systems applicability now exceeds US$ 7 billion with a projected growth rate of more than 25% by 2019 [5].

From aforementioned micro-fluidic devices, contribution of this study is mainly focused on the micro-channels and fluid flow analysis inside them. The novelty of the work involves transforming the straight micro-channel into new T-shaped channel geometry for multi-field analysis under certain conditions. From different types of fluids (methanol, silicon oil, gases, water), this study assumes water as a working fluid to visualize the flow pattern inside the T-shaped channel. The effect of parameters like pressure and velocity variation on fluid flow inside this newly designed geometry (T-shaped) of micro-channel has been studied.

II. ANALYTICAL FRAMEWORK

Micro-needle is a tiny glass needle employed in transdermal drug delivery system (TDDS) which is considered an emerging way of drug delivery since it has overcome the obstruction of outermost layer of the epidermis. Compact size and small length are the two factors which makes the micro-needle effective as compared to other hypodermic needles. The fabrication process of micro-needle involves poly silicon, metals, glass and polymers as fabricant materials while employed technology is the MEMS. With length of less than 1mm, micro-needle can be incorporated with multiple tiny devices like micro-pumps, micro-fluidic chips and biosensors in order to use it for versatile purposes.

Some applications of micro-needles involve; drug delivery, blood extraction, cancer therapy and dentistry. It is also considered a primary component in drug delivery systems. Actuation mechanism is provided by micro-pump to acquire the necessary volumes of therapeutic drugs. Micro-pump is comprised of; (i) chamber (ii) diaphragm (iii) actuator (iv) membrane and (v) micro-channel. Micro-pump is categorized in mechanical and non-mechanical parts, as shown in Figure 1.

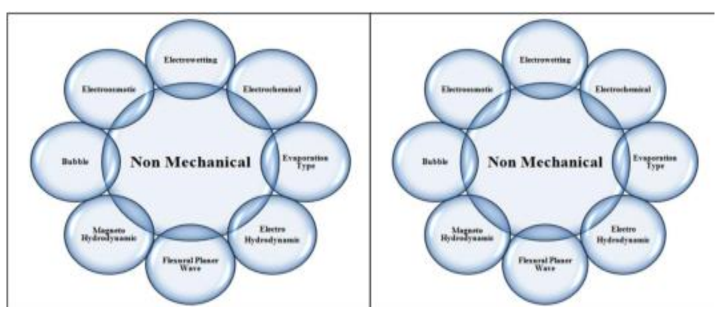

FIGURE 1. Types of micro-pump.

Micro-mixer is used in mixing the liquids featured to have the movement of micro parts. Two types of micro-mixer are (i) active and (ii) passive [6, 7]. The analysis of liquids flow and their characteristics is done through micro-fluidic devices extensively using micro-channels. Various types of micro-channel involve; straight, spiral, snake fang, curved and sinusoidal. The combination of multiple geometries with different radius is utilized in designing of micro-channels. By interfacing the configuration of curved micro-channel, double layer laminar liquid flow can be studied. The mathematical calculation of liquid flow as well as heat transfer could be done via periodic wavy channels.

Numerical analysis of liquid flow characteristics is carried out via Navier- Stokes (N-S) equation. The numerous formations of micro-channel including curved, sinusoidal, straight micro-channel, etc. are shown in Figure 2.

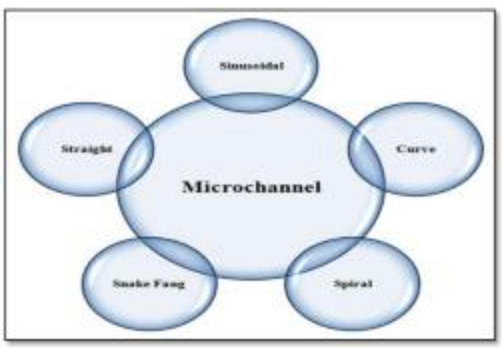

FIGURE 2. Types of micro-channel

In designing process, curve channels are fabricated on silicon substrate. The vital role during fabrication phase of channel is the physical characteristics of substrate [8-10, 11]. Dissipation effect (viscous) in laminar flow inside a curved channel is investigated when tow organic compounds (ethylene glycol, aniline) as working fluid using classical N-S equation [12].

Heat and flow transfer through sinusoidal passage has also been visualized. The selected flow was laminar in nature and the passage was wavy one. The aspect ratio of bounded wavy wall was 10:1 including length of 12-14m. Steady as well as unsteady behavior of fluid flow is considered. The phenomenon of mixing two or more fluids in homogenous form is based on two factors; (i) Reynolds number (ii) channel's geometry [12]. Two channels with dissimilar geometrical formation (i) arc shaped (ii) sinusoidal channels are employed to study the liquids flow features as well as heat transfer inside wavy shaped channel. Two forms of fluid flow which was 2-D steady and time dependent were considered. Value of Prandtl number (depends only on fluid and state of fluid) is 0.7. The channels having arc shaped geometry have the high friction parameter than sinusoidal [10].

The sinusoidal plate micro-channels which were symmetric in nature and organized in converging and diverging formation are discussed. The prescribed technique facilitates in controlling liquid flow traces during its motion in sinusoid channels. The liquid flow inside the channels is greatly affected by converging and diverging arrangement. Laser is used as visualization tool for fluid. 3-D heat transfer and laminar flow at low Reynolds number enhanced through sinusoidal channel has been investigated using CFD [5, 6]. The numerical study of convection (mode of heat transfer) and fluid dynamics in sinusoid shaped micro-channel is carried out to consider the effect of nano (small) particles inside the channels. Two parameters such as; (i) liquid flow at input inlet and (ii) walls, temperature of both taken into account. Nano scale liquid flow is observed for output analysis which includes copper-water [7].

Polymer electrolyte membrane (PEM) model of fuel cell was investigated in 3-D formation along with straight flow channel. Computational area of prescribed model comprised of anode as well as cathode liquid flow channel.

Different sorts of current density are applied showing shared characteristics of local current density. Distribution model is considered as comparatively deviating in nature at higher value of the current density and having an identical behavior at lower value of current density because of mass transfer restriction [8].

Dynamical behavior of liquid (water) transfer is analyzed in straight channel for PEM fuel cell cathode having manifolds. Gas channel definitely obstruct air/water in outflow manifold. Outflow manifold enhance the performance of fuel cell by enclosing large amount of water in a unit cell. Resistance (Ω) in membrane is mainly affected by water content [9].

Adaptive neuro fuzzy methodology is employed for the estimation of side weir discharging capacity that was triangular labyrinth in nature when kept on a straight micro-channel. Discharging coefficient is calculated using adaptive neuro fuzzy interference system (ANFIS) for triangular labyrinth side weirs. Numerous linear and nonlinear deterioration prototypes are the main parameters for comparison study between two; one is the radial basis neural networks (RBNN) and other one is feed forward neural networks (FFNN), when two different neural techniques are employed on straight micro-channel [2, 8-10]. Discharging coefficient of fluid flow is calculated for open channel which was straight in nature [12].

Electro-osmotic fluid flow inside a split channel which has been comprised of two parallel walls having zeta potential is studied. The working fluid is transient in nature. Partial differential equation is calculated by combining the momentum equation with Maxwell model to determine the velocity profile of fluid through the micro-channel. The resultant velocity profile shows symmetric, asymmetric formation and oscillatory behavior during the transient stage of fluid flow [12]. The diagnosis of disease for individuals and therapy using MEMS based technology is an innovative track for future medication. Implantable, programmable and refillable MEMS based chemotherapy drug transfer method is used for treatment of pancreatic cancer [2-6]. Flow phenomenon in parallel channel severely affecting the process of hot spot formation as well as distribution of temperature in micro devices.

The key purpose behind this work is to explore the factors (Reynolds number, hydraulic diameter, cross section area, number of channels) affecting prescribed phenomenon causing pressure decrease through the manifolds of parallel channel is employed for cooling of CPU [2-5]. Therapeutic magnetic micro-beads are used as navigable agents considered as progressive method of target drug delivery controlled by magnetic gradients. The controllability and observability analysis is made for multiple micro-beads as well as linear control technique termed as linear quadratic employing integral function (LQI) that is applicable on magnetic micro-beads system. The process of precise transport of drug is perfectly done through micro-needle and micro-pump. Piezoelectric micro-pump having poly dimethysiloxane (PDMS) film and SU-8 hollow cavity micro-needle is used for finite element analysis. The fluid pattern observed in pump chamber is laminar in nature [2-7].

In this paper, a straight micro-channel is considered having the T-shaped geometry, through which micro-fluidic analysis has been examined to measure pressure and velocity variations inside the channel.

III. STRUCTURE DESIGNING OF T-SHAPED MICRO-CHANNEL

The straight channel having T-junction is discussed in this paper. Micro-channel in 3-D formation is designed using ANSYS. In designed geometry of the micro-channel, straight channel has length of 500µm, T-shape is 200 µm long and diameter of channel is 50 µm. Geometry of proposed channel is shown in Figure 3.

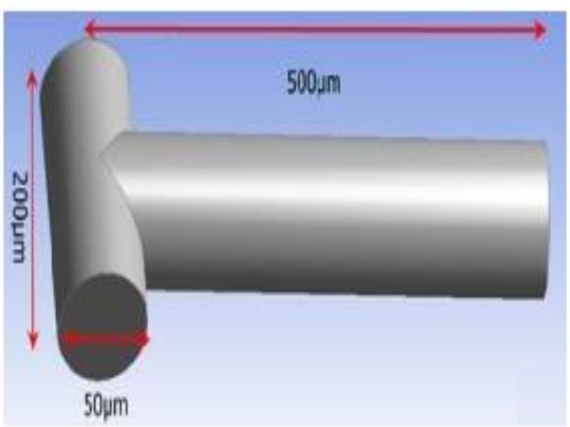

FIGURE 3. Designed T-shaped channel

IV. PRINCIPLE OF LIQUID FLOW

Channel is a closed shape medium through which any form of liquid can flow. It may comprises of formations including; large, small, artificial and natural containing of arteries and veins. It has been considered as base medium for transportation of liquids and gasses. The main constitutes of any channel are inlets and outlets. Two types of liquid flow is primarily considered through channels; (i) Turbulent flow (ii) Laminar flow. To know about the specific form of fluid flow, viscosity and inertial flow are the important parameters.

Motion of fluid (liquid) containing certain types of pressure and velocities varied on random basis is called turbulent flow. Turbulent flow is most commonly observed in non-viscous liquids having large velocities variations. The major categorizing parameters of turbulent flow are; diffusion, dissipation, irregularity and rationality. Turbulence is an unsteady parameter mainly caused by shear. When the shearing is large, turbulence become cohesive. Turbulent phenomenon of liquid flow take places having the Reynolds number value above 4000. Flow pattern for liquids will be changed from the laminar form into turbulence, when the value of Reynolds parameter is lying among 2000-4000 [2-8].

Steady, continuous and smooth motion of viscous fluid (liquid or gas) is termed as laminar flow. Pressure, velocity and other flow characteristics are remained constant in laminar flow, therefore also termed as streaming flow. The two main categorizing factors of laminar flow in fluid dynamics are; (i) lower values for momentum convection (ii) higher values for diffusing momentum. This type of fluid flow exists only, when having the value of Reynolds number lower than 2300 and at relatively higher velocities. Laminar is totally an opposite phenomenon to turbulent flow while considering the fluid dynamics [9]. The steady and smooth fluid behavior of laminar flow is shown in Figure 5. Reynolds number plays a vital role in turbulent and in laminar fluid flow. Inertia and viscous are the two main forces in fluid dynamics to distinguish the type of fluid flow whether it is laminar or turbulent in nature. Laminar type of liquid flow occurs only, when having inertial forces magnitude lower than viscous forces magnitude and turbulent type of flow exists only having greater value of inertial forces.

The numerical calculation of Reynolds number can only be done by division of kinematic viscosity during the stage of inertial forces for liquid flow.

V. SIMULATION ANALYSIS

In this paper, straight micro-channel having T-junction is to be taken for visualizing the multi-field analysis. The value of static pressure taken is the 100 KPa in magnitude is applied at input side (inlet) of straight channel. Value of pressure at output side (outlet) of channel is 0 Pa. While, water is used as working fluid at 25C. In the early stage of simulation, 3-D geometry of the T-shaped channel through ANSYS CFX-solver is designed as shown in Figure 4.

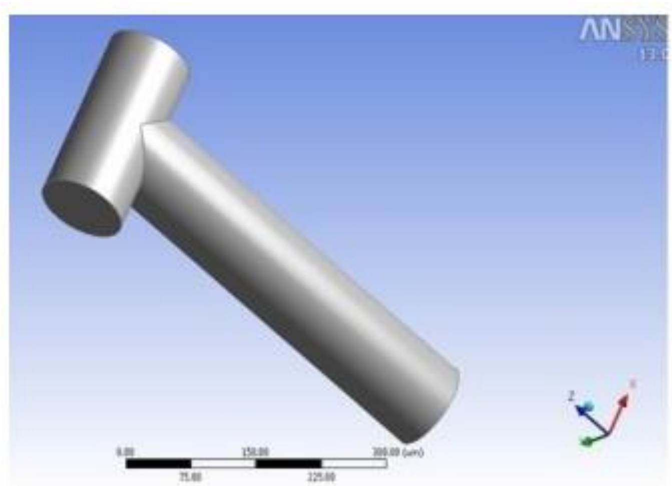

FIGURE 4. 3-D geometry of channel.

The main parts of 3-D formation of designed channel has been defined and termed as; (i) inlet (ii) outlet (iii) walls. After that meshing has to be performed for finite element analysis on the designed system model of micro-channel to acquire the appropriate and effective multi-field solution. In the next stage, meshed model is imported into CFX-Pre window. After that boundary, domain and initial conditions are defined.
To visualize the fluidic behavior inside the micro-channel, water which is a working fluid is entering the channel with an initial pressure of 100 KPa. After applying an initial high pressure with which fluid enter the micro-channel through inlet, the value of pressure then reduced to a value of 0 KPa. As a result, fluid will come out through the outlets of the channel. The roughness of inside walls of T-shaped micro-channel is assumed to be smooth for steady movement of fluid through channel.

VI. RESULTS AND DISCUSSION

Pressure and velocity are the main parameters which are affecting the fluid flow inside the T-shaped channel as well as their effect is analyzed at micron level.

A. Pressure changes inside the T-shaped channel

Initially, fluid (water) enters the T-shaped channel with an inlet pressure of 100 KPa. Since, water is viscous liquid with density of 1000 kg/m inside the straight channel, having viscosity of 0.00133 Pa. with a Reynolds number of R = 4511. As for the case of liquids, having Reynolds number greater than 4000 will exhibit turbulent flow inside the micro-channel. Turbulence is an unsteady flow pattern of liquid, therefore, after certain interval of time, collision of fluid with walls of channel resulting the periodic change of pressure values. The designed geometry (T-shaped) has smooth walls showing that roughness of the walls is ignored or assumed to be zero. We are considering an ideal case for working conditions of fluid; therefore, according to the prescribed conditions of working fluid, pressure value should also be the 100 KPa experimentally as well. It can be observed from the Figure 16 that how the above mentioned conditions are affecting fluid motion through T-shaped micro-channel and the graphical plotting of pressure variation along the channel length (chart count). When pressure value is reduced to zero at the inlet, working fluid will come out through the outlets of channel.
While outlet pressure is 0 KPa. Fig. 5 shows that maximum attained value of pressure is almost 100 KPa through the micro-channel, while motion of fluid flow inside the T-shaped channel. This maximum value of pressure is equivalent to the applied inlet pressure. The novelty of the work presented in this paper is that for an ideal case of fluid flow inside the T-shaped geometry of designed micro-channel, the applied inlet pressure of 100 KPa can be visualized during fluid flow through the micro-channel and it can be observed from Fig. 5 showing the pressure changes inside the T-shaped channel.

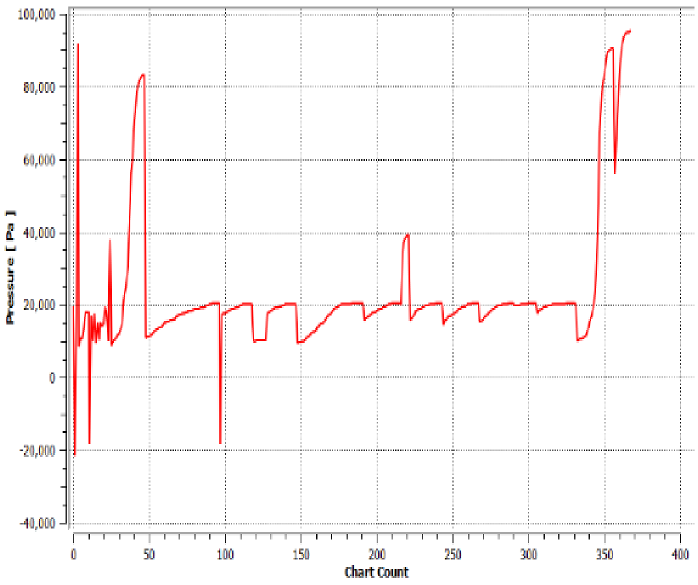

FIGURE 5. Pressure changes inside the channel.

B. Velocity changes inside the T-shaped channel

When fluid flow through the T-shaped micro-channel, there must be the changes in velocity value through the channel's length also termed as chart count which is presented in Figure 17. It can be seen that maximum value of velocity achieved while motion of fluid inside the channel is 13 m/s. From Fig. 6, it can be confirmed that for the inlet pressure of 100 KPa, maximum change in velocity value can be observed which is 13 m/s.

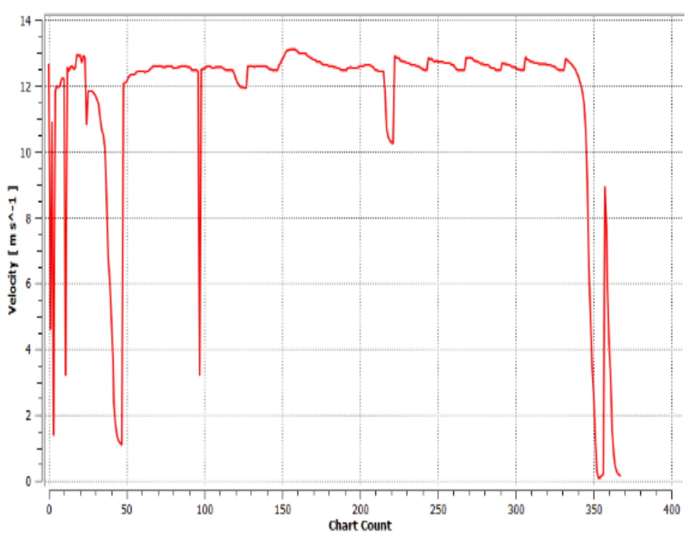

FIGURE 6. Velocity variation through channel

C. Simultenous analysis of pressure and velocity variation inside the T-shaped channel

To visualize pressure and velocity change inside the T-shaped micro-channel for provided input and output condition, a combine plot between pressure and velocity is shown in Fig. 7.

It can be observed from the resultant graph that pressure decreases with respect to velocity initially.
Since, fluid flow (water) is turbulent in nature, therefore, after colliding with the walls of T-junction of micro-channel, value of the pressure is significantly decreased again in comparison with velocity value which is increasing continuously, but now changes in pressure value is in opposite direction because of T-junction of micro-channel which is a unique feature of fluid flow inside this designed T-shaped channel as shown in Fig. 7.

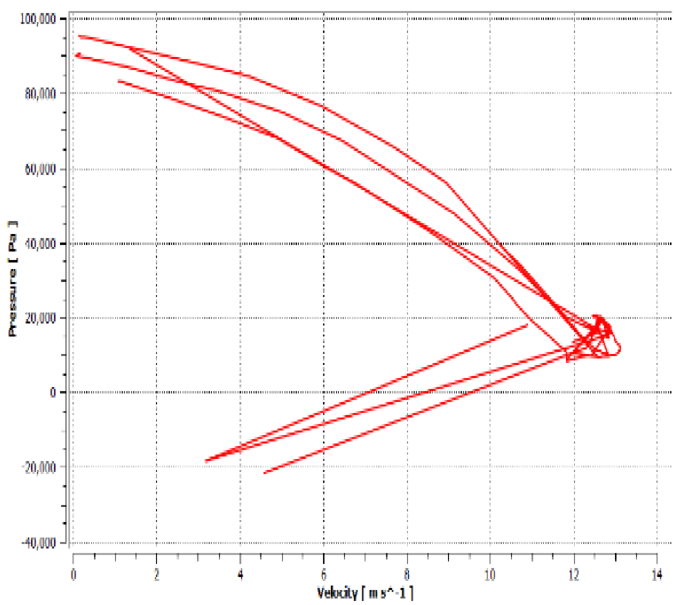

FIGURE 7. Pressure against velocity

VII. CONCLUSION

Micro-fluidic analysis of fluid flow (water) inside T-shaped micro-channel is visualized experimentally using the ANSYS CFX-solver. For the first time, straight channel having T-junction like geometry has been considered for multi-field investigation at such a micron level. The main purpose of the work is to design a unique geometry of micro-channel (straight channel having T-junction) and from numerous fluids (methanol, silicon oil, gases, water), water is considered as working fluid through designed channel. The effect of two basic parameters, pressure and velocity variation is analyzed during motion of working fluid via channel. In order to consider the effect of these varying factors (pressure and velocity), some conditions have been applied while geometry design, on inlet and outlets of the micro-channel. Static pressure having the magnitude 100 KPa is applied at inlet end and outlet pressure has the value of 0 KPa. While, water is taken as working C in an isothermal domain. Geometry of the designed micro-channel comprises of 500 µm fluid at 25 degree length of straight channel, having diameter of 50 µm and T-junction having length's value of 200µm. Surface parameters involving inlet, outlet and walls of 3-D model are defined initially.
After that brick meshing is performed via Solid_186 Element on 3-D model of micro-channel. Domain and boundary conditions are also defined for designed model. The results are obtained after running the ANSYS CFX-solver. The pressure and velocity variation is visualized by contour, vector and streamline flow. It can be observed that maximum velocity of 13 m/s is attained via micro-channel at an applied inlet pressure of 100 KPa. The novelty of work is shown in output results displaying significant decrease in pressure value in accordance with velocity, after collision with T-junction, pressure value is decreased again but in opposite direction because of T-junction of designed micro-channel.

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