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Investigations of Nutrient Flow through Microfluidic Channels for Medical Applications

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***Abstract*—**Microfluidics, a science of controlling and manipulating fluids or gases, is an emerging research field and finding its utilities in biotechnology, nanotechnology, information technology, engineering, physics and chemistry. The size, shape, material, temperature, pressure and the orientation of the microfluidics channels affect the fluid flow. The objective of this paper is to analyze the effect of pressure on the velocity of fluid flowing through microfluidic channel. The investigations were carried out at two angles. The analysis shows that the flow of fluid is angle and height dependent.

***Keywords*—**Microchannel; microfluidics; pressure; velocity; PDMS.

I. INTRODUCTION

The most complex part in this universe is the understanding the complexities living beings. Human body is the most complicated living being on earth. Each organ inside the body is meant for performing a specific function. The cardiovascular system helps in transporting essential nutrients, hormones and cellular wastes throughout the body with the help of heart and blood vessels. There is a dense mesh of nerves, capillaries veins, arteries and neurons inside our body. The total length of blood vessels in our body is about 60000 miles. Arteries are thicker and more elastic than other vessels so as to accommodate the high pressure that forces the oxygenated and purified blood out of the heart. The thinner areas of the arteries pump out the blood at high pressure. The veins provide reverse function as it carries unpurified blood back to heart [1]. Capillaries are the thinnest of all blood vessels running through every tissue of the cells and providing the cells its required nutrients and carrying out the waste out of it. Molecules less than 3nm such as water, ions and gases cross through the space between the cells. A capillary consists of only a thin layer of endothelium allowing only a thin structure between blood and tissues. The average diameter of capillaries is 5 to 10 microns in human [2]. Capillaries perform the same function in plants to carry water and nutrients from roots to each part of the plant. The water molecules sticking to the soil are attracted towards the roots which are then taken to stem and other parts and this occurs when the force to attract water up is more than the gravity of the earth. Water climbs up in the thinner capillaries more than capillaries with large diameter comparatively [3]. The equation for determining the height of capillary action is h=0.3/d where d is the diameter of capillaries and height of rise. Tall trees have thinner capillaries to suck water and other necessary nutrients from the soil to the top of the plant [4-6]. There are techniques for growing plants too in which roots and submerged in solution of nutrients and water fully saturated with oxygen. The roots uptake the required supply and this technique is known as solution culture or hydroponics. Soil is not required in this case to grow plants. The main function is performed by the capillaries in the plants which are just like the capillaries in other living beings. The capillary action is similar to microfluidics which is the studying the behaviour of different fluids [7].

Microfluidics is studying the behavior of fluids processing or manipulating small quantity of fluids of about 10^{-9} to 10^{-18} liters through pores of diameters ten to hundreds of microns. This field is a combination of physics which deals with the behavior of liquid and controlling liquids at micro scales. The creation of microfluidics is microelectronics fabrication [8-12]. It has the potential to change the way the modern techniques are carried in every field requiring small amount of volumes of fluid for experimenting, smaller reaction time as compared to others. The effects that become dominant in microfluidics include laminar flow, diffusion, fluidic resistance, surface area to volume ratio, and surface tension. Fluid flow and control of different fluids are to be taken care of. Microfluidic chips are fabricated using silicon, glass or polymer [13], [14]. Both conventional and non-conventional methods such as micro milling, lithography, are used for fabrication. A conventional method of fabrication includes etching of microchannels on glass and silicon. But this method proves to be very expensive. The material is to be selected depending upon the application in which it is to be used. For superior thermal conductivity, surface stability and solvent compatibility silicon and glass are used. Polymers are not suitable for above specified applications but they are cheaper and require less fabrication time. Polydimethylsiloxane (PDMS) is the most common polymer used for fabrication by soft lithography with the disadvantage of getting deformed under high pressure [12], [15].

II. FUNDAMENTALS OF MICROFLUIDICS

Fluid is the main constituent that is affecting the whole mechanism. Its properties like density, specific weight, relative density, viscosity, Reynolds numbers is to be taken care of while designing a specific application. The fluid mechanics/flow is governed by the above specified properties.

1. Reynolds number is a dimensionless velocity/quantity which predicts the similar flow patterns in different fluid flow

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situations. It is the ratio of momentum forces/inertia forces to viscous forces.

$$R_e = \frac{\rho v l}{\mu} \quad (1)$$

$$l = \frac{4A}{P} \quad (2)$$

Where v is the average velocity of flow of fluid, l is the distance travelled by the fluid in the channel, A is the cross sectional area of the channel, P is the actual wetted perimeter of the channel, ρ is fluid density, and μ is the dynamic viscosity of the fluid.

Reynolds is a function of properties of the material, boundary conditions and velocity. Different parameters are to be taken consideration of depending upon the channel through which the fluid is passing. Fluid flow can be laminar, transient and turbulent [15], [16].

Laminar flow occurs when fluid flow in parallel layers and no disorder is between the layers. Even hindered, the fluid flow as it is as shown in Fig. 1. It occurs at low velocities. The motion of the particles flowing is parallel to the wall of the channel. The laminar flow is used to separate volumes of air or preventing airborne contaminant from entering. The fluid flow is laminar for Reynolds value less than 2300 [17]. Fig. 1 shows the laminar flow of fluid obstructed by a solid sphere and Fig. 2 shows the turbulent flow.

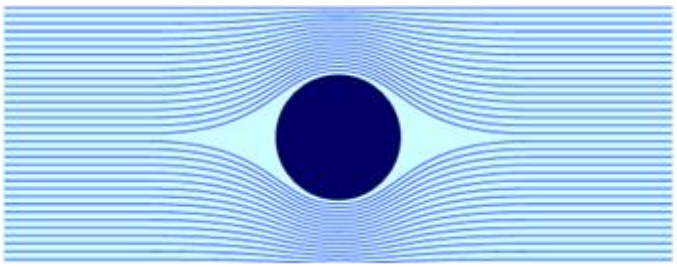

Fig. 1. Laminar flow obstructed by a spherical object.

Turbulent flow is the laminar flow at higher velocities. In turbulent flow the curling of field lines of fluid occurs as shown in Fig. 2. The Reynolds number >4000 for turbulent flow. The flow is characterized by changes in chaotic properties. Unsteady vortices are noticed here at many scales interacting with each other.

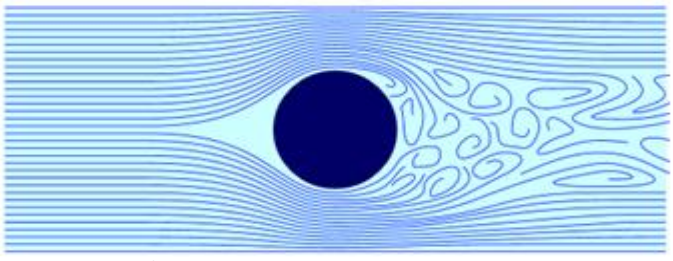

Fig. 2. Turbulent flow obstructed by a spherical object.

Transient flow is a periodic flow and it covers surface waves and acoustic waves. The Reynolds number lies between 2300 to 4000.

As discussed above the Reynolds number is dependent upon the material, fluid, dimensions of the channel, so any change in it will affect the Reynolds value which will indirectly effect the laminar or turbulent flow. Channel imperfections while designing effects the control of fluid and it may lead laminar flow to change to turbulent flow. Microfluidics includes bubbly flow, slug flow, churn flow or annular flow [16], [18].

2. Density and Specific Weights: Density and specific weights of the fluid are temperature dependent. Density is mass per unit volume, so value of it is specific and it will stay same for a specific mass and volume, whereas specific weights depends upon the location as g is to be taken care of while calculating specific weights [18], [19].

3. Specific Volume and Specific gravity: Specific volume is the volume occupied by unit mass of fluid. Specific volume is the reciprocal of density and is applied for gases and Specific gravity of a fluid is the ratio of density of fluid to the density of water at standard temperatures [20].

4. Viscosity: Viscosity of a fluid is measure of the fluid resistance to its own flow. Fluids oppose the motion of the particles immersed in it and the motion of the layers with differing velocities as the velocities differ from centre of channel to the wall [19], [21].

III. Applications of Microfluidics

There are uncountable application of microfluidics in microbiology, microelectronics, military, medical sciences etc. The threat of biological war was one of the reasons which give birth to microfluidics and rapid growth in microfluidics technology serves as a means to detect the biological dangers. The microfluidics will sense the fluid or gases in the air and raise an alarm for the biological threat. Work is going in the field of hospital on a chip, which is under development keeping in view the military requirements. The system will monitor the health condition of a soldier from his tears, sweat or blood. Most of the deaths in the battle field occur 30 minutes of the wounds/injuries. Before taking the injured to the medication site, the deaths occur. This device will monitor the condition of the soldier using microfluidics device and start its treatment by releasing medication determined by the already fed in the pattern and this will help him in sustaining his life before getting proper medical help.

1. Drug delivery: The present system of intake of medicines is inefficient as besides curing, it cause lots of other side effects. To treat chronic inflammation in a patient, the patient is given some oral medicines whereas the field of microfluidics will help to release the required amount of medicines into the infected part/wounded part. The microfluidics allows a controlled flow to the desired cells or tissues in the skin. It will cure an infected cell or tissue. Nano particles or Nano-medicines can be inoculated through these microchannels with ease. The infected cancer cells can be cured using Nano medicines. Microfluidics gradient generators are employed to

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manage the flow of drugs on cellular basis. Drug inoculated can be done at the cellular level or tissue level using micro needles. The micro needles can be made hollow to inject medicines or such that it encapsulates drug into it and is absorbed into the cell provide the material of the microneedle is cell friendly or organism friendly [22].

2. Stem Cell Biology: Stem cell biology is an emerging field in microfluidics. Stem cell divides due to mitosis and double their number after every division. Knowing the biology behind the stem cell using microfluidics will let us root out each and every problem like cancer [23].

3. Microfluidics in Research: Microfluidics have led to the development of microchannels and study of the properties of ultrasensitive bio analytical devices. It finds its application in pollution monitoring and analysis of complex biological samples. Even single cell can be isolated, analyzed and manipulated. It allows introducing the required material and extracting the desired material from the cell lying the prospectus of controlling every factor responsible in growth [24], [25].

4. Microfluidics in Electronics: Microfluidics tablets which will flood the market soon. When the tablet is hold, the physical keys appear to rise up the screen. The height of the buttons can be controlled by the amount of fluid carried in them. They are traditionally different from the hard keys and assist the blind people as well. The microfluidic keyboard is the mark of setting revolution in the field of microelectronics. Microfluidics is being applied to improve the solar efficiency [26], [27].

III. METHODOLGOY

The experiment was carried on the microchannels to test the effect of pressure on velocity of the fluid. The first step is the fabrication of microchannel of width 500 microns and depth 180 microns with dimensions of 4mm. Lithographic techniques had been used to fabricate the micro-channels on silicon (Si) substrate. The substrate was cleaned and pre-baked for 5 min at 90 ºC for dehydration process. The substrate was coated with SU-8 photoresist and exposed to UV light, creating patterns over the resist. The resist was developed for 15 min using MSDS SU8 developer. The patterns were examined under microscope. The designed patterns of SU-8 were transferred over PDMS. Liquid PDMS was mixed with cross linker agent Siloxane in 1:10 ratio. Any increase in this ratio increases the rigidity of PDMS. All the air bubbles were carefully removed from the mixture and it was poured over the substrate. After the PDMS was dried, it was ready to peel and used for further processing. The microchannel so fabricated was sandwiched between two glass slides. Fig. 3 show the microchannel inserted between the glass slides and Fig. 4 shows the dimensions of microchannel under microscope.

Before inserting the microchannel PDMS, the slides were cleaned with acetone. Y shaped PDMS was cut at the two ends. One end was used as inlet and the other acted as outlet whereas the third one was kept as it is. A microneedle of 150 microns was taken and inserted into the input and fixed with silicon gel. This microneedle was attached to the glucose pipe. The flow of glucose level was controlled by the knob which was adjusted to allow the maximum flow of glucose. The height of the glucose bottle was adjusted with the stand. The rate of flow of fluid was taken at different pressures by changing the height of the glucose level with respect to the channel. A camera was fixed to check the rate of flow of glucose through the microchannel. Fig. 5 shows the image of the whole assembly.

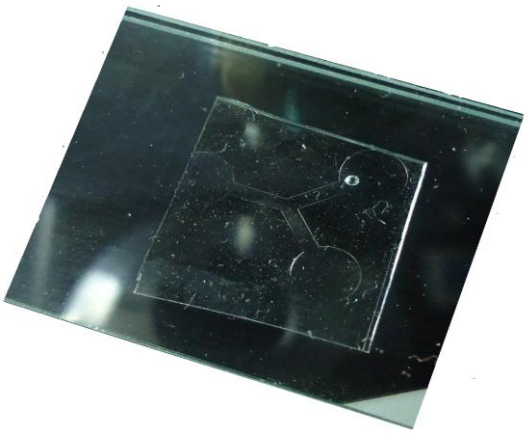

Fig. 3. Microchannel sandwiched between the glass slides.

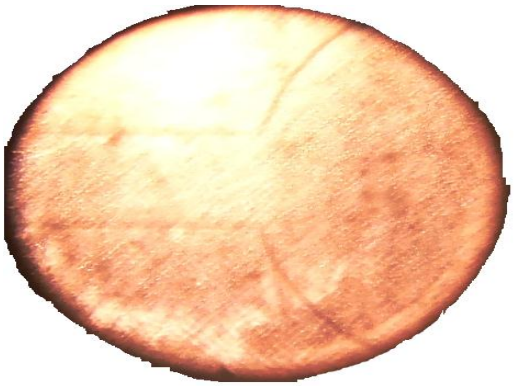

Fig. 4. Microchannel as seen under Microscope.

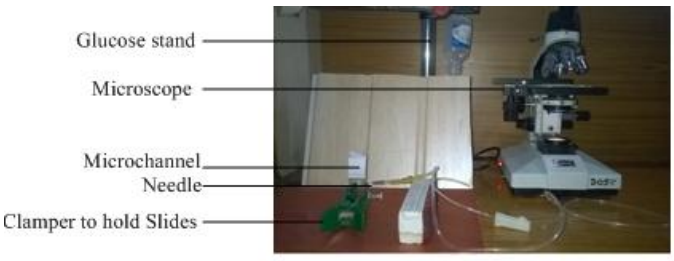

Fig. 5. Whole assembly setup of the experiment.

The readings were taken in two parts. In first part, the microchannel was held vertically and the glucose was made to run through the microchannel. Video was shot to check the rate of flow of fluid. Same process was repeated at varying height. In the second part, the microchannel was held

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horizontally and the same process was repeated at varying height. The videos were converted into images and the flow of glucose at different time intervals was noted. Fig. 6 shows the flow of glucose through the channel (kept at an angle of 90^0 w.r.t the ground) covering a distance of 1mm in 24.25 ms at a pressure of 10715.32 Pa.

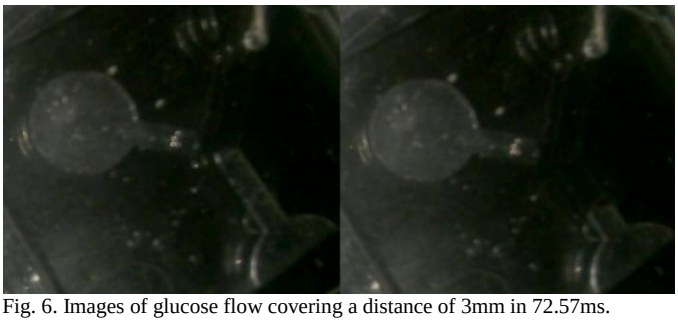

Fig. 6. Images of glucose flow covering a distance of 3mm in 72.57ms.

The images given in Fig.7 shows the flow of glucose through the channel (set at angle of 0 degree w.r.t. ground) covering a distance of 0.5mm in 38 ms at a pressure of 10836.06 Pa.

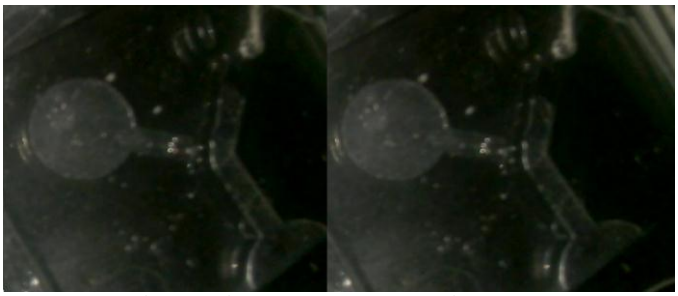

Fig. 7. Images of glucose flow covering a distance of 0.5mm in 38ms.

III. RESULTS

Table 1 shows the average velocity of the glucose flowing through the channel at different pressure. Fig. 8 and Fig. 9 shows the pressure verses velocity graphs of the microchannel set at an angle of 90^0 and 0^0 w.r.t. ground. Velocity of the fluid flowing through the Y shaped microchannel increases with increasing pressure by indirectly increasing the height of the glucose level. The flow of glucose remains laminar throughout.

Table 1. Pressure and velocity relationship.

ANGLE W.R.T. GROUND

90 DEGREE		0 DEGREE	
PRESSURE (Pa)	**VELOCITY (mm/s)**	**PRESSURE (Pa)**	**VELOCITY (mm/s)**
7847.84	3.164556962	**7968.576**	6.688963211
10715.32	41.2371134	**10836.06**	13.15789474
13582.8	125	**13703.06**	13.88888889
		16571.02	31.25

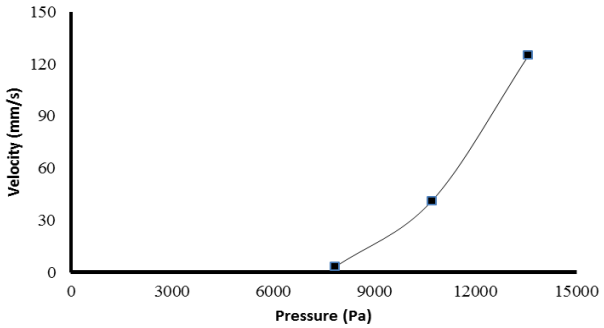

Fig. 8. Variation of velocity with pressure for microchannel set at an angle of 90^0 with respect to ground.

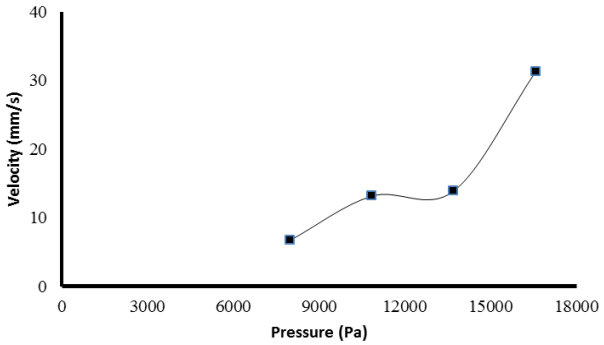

Fig. 9. Variation of velocity with pressure for microchannel set at an angle of 0^0 with respect to ground.

IV. CONCULSION

The objective of the paper was to check how the flow of fluid through microchannel is affected by change in pressure. It was concluded that velocity of glucose is affected by change in pressure. Our future motive is to design a microfluidic bandage that will replace the common bandage available in the market now days. To design such bandage we need to study the effect of different fluids at different pressure and temperature and obtain a generalized analysis. Microfluidic channel can be used instead of roots in future. The rotten roots of the plants are to be replaced with the microchannel and Plants will be grown without soil and necessary nutrients supplied through microchannel attached with the stem.

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