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Numerical Analysis of Velocity Profile in a FFS Microchannel

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ABSTRACT

Manipulation of the fluid flow behavior in microfluidic with precision technique is crucial to satisfy the needs of miniaturized systems. Velocity measurement is one of the physical phenomena plays significant role to determine the performance of a microfluidic channel. This article presented the simulations of liquid with laminar flow over forward facing step microchannel to study the velocity profiles. Various Reynolds numbers and two different step heights have been used as main parameters. Higher Reynolds numbers and step height have been observed to produce higher flow velocity distribution. The peak velocity is found on the center of the channel across the x-axis.

INTRODUCTION

The development in biological and chemical field towards miniaturization motivates to the robustness of microfluidic technologygrowth.Miniaturized systems appliedfor tumor spheroid culture[1], transdermal drug delivery[2], sperm-sorting device[3], bacteria biofilms analysis [4], urinary protein detection[5] and DNA separation [6]are examples of integrated technology of microfluidic and other related fields. The potential of microfluidic devices to control and process of small amount of fluids leads to dramatic reduction of sample and reagent volumes[7]. Other attractions lie in cost and time saving and enhancement of sensitivity and reliability of the devices [7].

Concentrating on biomedical diagnostics, George Maltezos et al. have designed and fabricated a microfluidic blood filter by improvising the recent device structure and function.Previously, some of the blood filter devices are incapable to operate the whole blood without manual sample preparation and some face structure issues. Therefore, for the proposed miniaturized system the filter is tightly sealed and equipped with anti-coagulant EDTA coated capillary tube. By enhancing the filtering part capacity, it able to process the whole blood directly from a single fingertip prick. Overall, it is a simple, low cost, compatible and disposable blood filter device. M. Moschallski et al. (2009) presented a microfluidic chip for DNA detection from bacteria. Three main step flows have been implemented on the urine testing sample to extract E.Coli. Initially, positive dielectrophoretic process is conducted in low electric conductivity medium to collect and accumulate bacteria from the sample. Subsequently, the bacteria cells are lysed after the fluid flow is stopped and the electric field frequency is reduced. Finally, the bacteria DNA released and proceeded with analysis using real time PCR. This miniaturized system is not just integrated the complete process on a microchip but has the potential to be automatized. A miniaturized Vertical-Cavity Surface-Emitting Lasers (VCSEL) based system has been fabricated by B. Reig, V. Bardinal, T.Camps, J.-B. Doucet and E.Daran integrated microfluidic and optical sensing system. This design enables real time cell analysis (cytometry) in a microfluidic system. The microfluidic channel concentrated on the suspension and detection of biological cells. In addition, the optical system fabricated with a tunable microlensattached to the surface of VCSEL laser diode for dynamic focusing on VCSELs array. Thomas, Ron and Bernhard (2002) underlined that laminar flow behavior of fluids in microfluidic devices is primarily important to accommodate with the design and development of the miniaturized systems [11]. Thus, this paper will investigate on the laminar

flow velocity profile over forward facing step microchannel. Various Reynolds (Re) numbers have been employed to study the flow velocity characteristic on the step height of 25% and 75% from inlet channel height.

Methodology:

The microchannel was modeled and simulated using Ansys software to visualize the flow characteristic. Initially the grid independence test was performed to obtain the most accurate resultin the final simulation. The microchannel was separated into five parts, which has been meshed and simulated by separately as depicted in Fig. 1. A total of 2560k nodes were obtained.

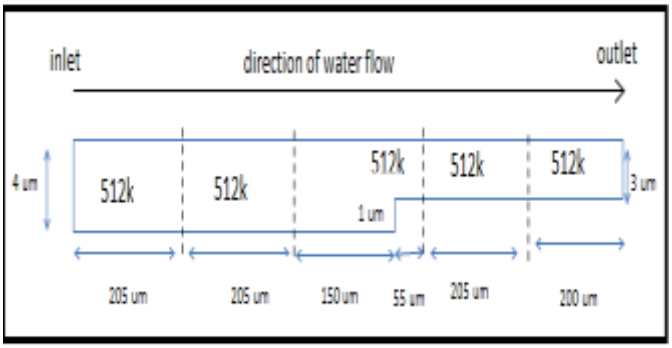

Fig. 1: Sketching of five parts meshing, yielding around 2560k nodes

In this work, the microchannel was designed with length of 1000µm and step location at Z=550µm from inlet. The velocity distribution was observed at location, Z=750µm from inlet channel after considering fully developed flow. Therefore, part four was concentrated and illustrated in Fig. 2. The size of the inlet channel is 4µm x 4µm and the step height tested was 1µm and 3µm which represented 25% and 75% from inlet channel height respectively. Six Re numbers used to assess the fluid flow behavior; 0.1,1,10,100,300 and 500. Water has been chosen as the working fluid. Laminar flow profile was used for the simulation analysis.

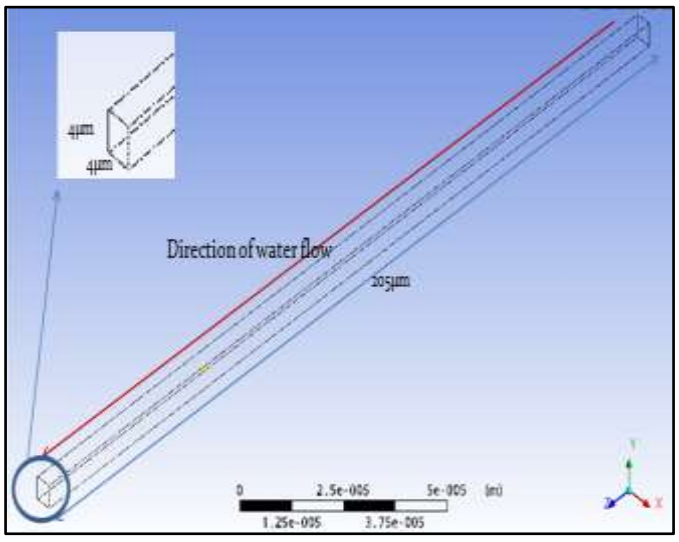

Fig. 2: Analysis at Z = 750µm from part 4

The different value of Re numbers contributed to the different value of inlet velocity. Inlet velocity value for each Re number may be referred as in Table 1.

Table 1: Inlet Velocity For Reynolds Number 0.1, 1, 10, 100, 300, And 500

Re numbers	Inlet velocity (ms^{-1})
0.1	0.0223
1	0.223
10	2.232
100	22.32
300	66.948
500	111.58

RESULT AND DISCUSSION

The velocity profile across the x-axis channel at Z=750µm for step height 1µm is illustrated in Fig. 3. A parabolic manner is obtained for all Re numbers.The highest velocity value is observed on the center of the channel (2µm) but approaching to zero near the wall region. This is due to interaction between liquid-solid near the wall channel. Further increase in Re numbers resulted the increasing of velocity. Higher Re numbers experience higher momentum among the molecules which contribute to increasing of the velocity distribution. Thus, the highest velocity profile is noticeable at the biggest Re number, 500.The flow of water for Reynolds number 0.1 is a steady with a smooth flow which can be assumed as completely laminar.

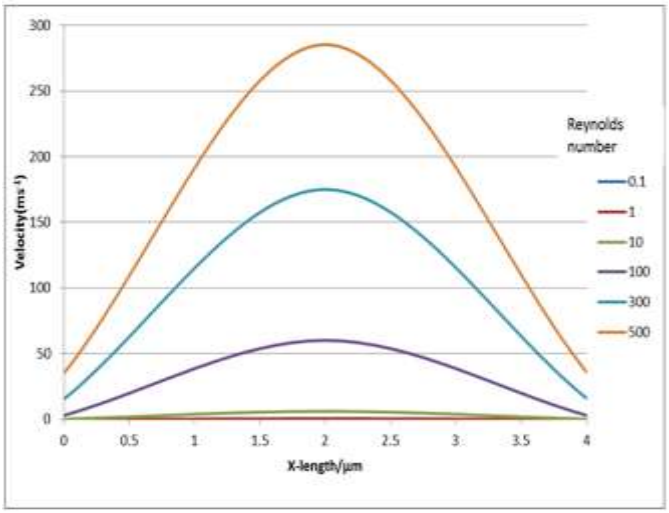

Fig. 3: Comparison velocity profile for the Re 0.1,1,10,100,300,500 for step height 25% (1 µm)

To study the effect on the height of step toward the fluid flow behavior, second simulation was conducted by changing the height from 1µm to 3µm. The velocity distribution across the x-axis channel at Z=750µm is shown in Fig. 4. The increment of the step height reduced the cross section area after step. Basically, when the fluid is flowing through a narrower channel, the fluid's kinetic energy increase causing the liquid flow accelerates. As a result, higher step height will cause fluid flow velocity arises.

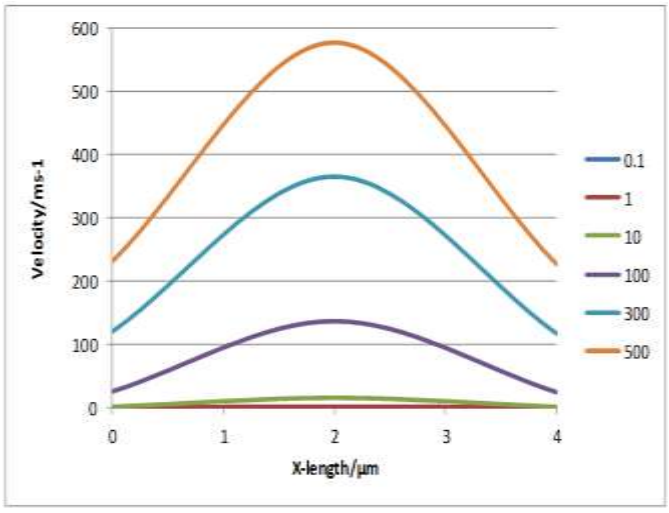

Fig. 4: Comparison velocity profile for the Re 0.1,1,10,100,300,500 for step height 75% (3 µm)

Fig. 5 and Fig. 6 demonstrated velocity contours of the fluid flow in microchannel for Re from 0.1 to 500 for both step heights 25% and 75% respectively. As discussed earlier, the highest velocity appeared at the center of the microchannel for all Re which represented by the red color contour while the blue contour for the minimum velocity dominated close to the wall region. The increase of the velocity distribution is visibly observed after the fluid flowed passing through the step. On the other hand, the speed of the liquid movement is found to increase rapidly for step height 3µm compared to 1µm.

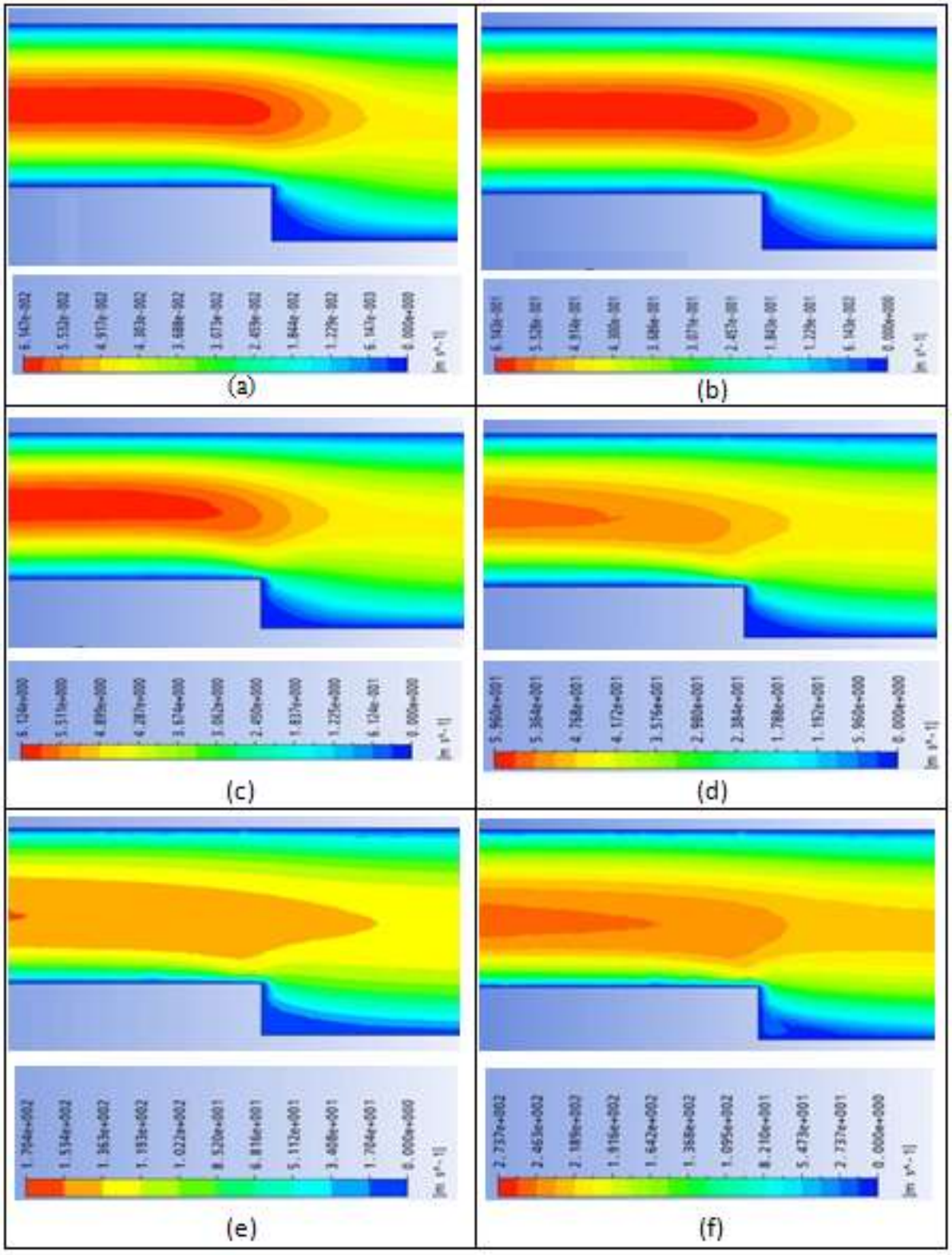

Fig. 5: Analysis velocity contour at 25% step with different Re (a) 0.1, (b) 1, (c) 10, (d) 100, (e) 300 and (f) 500

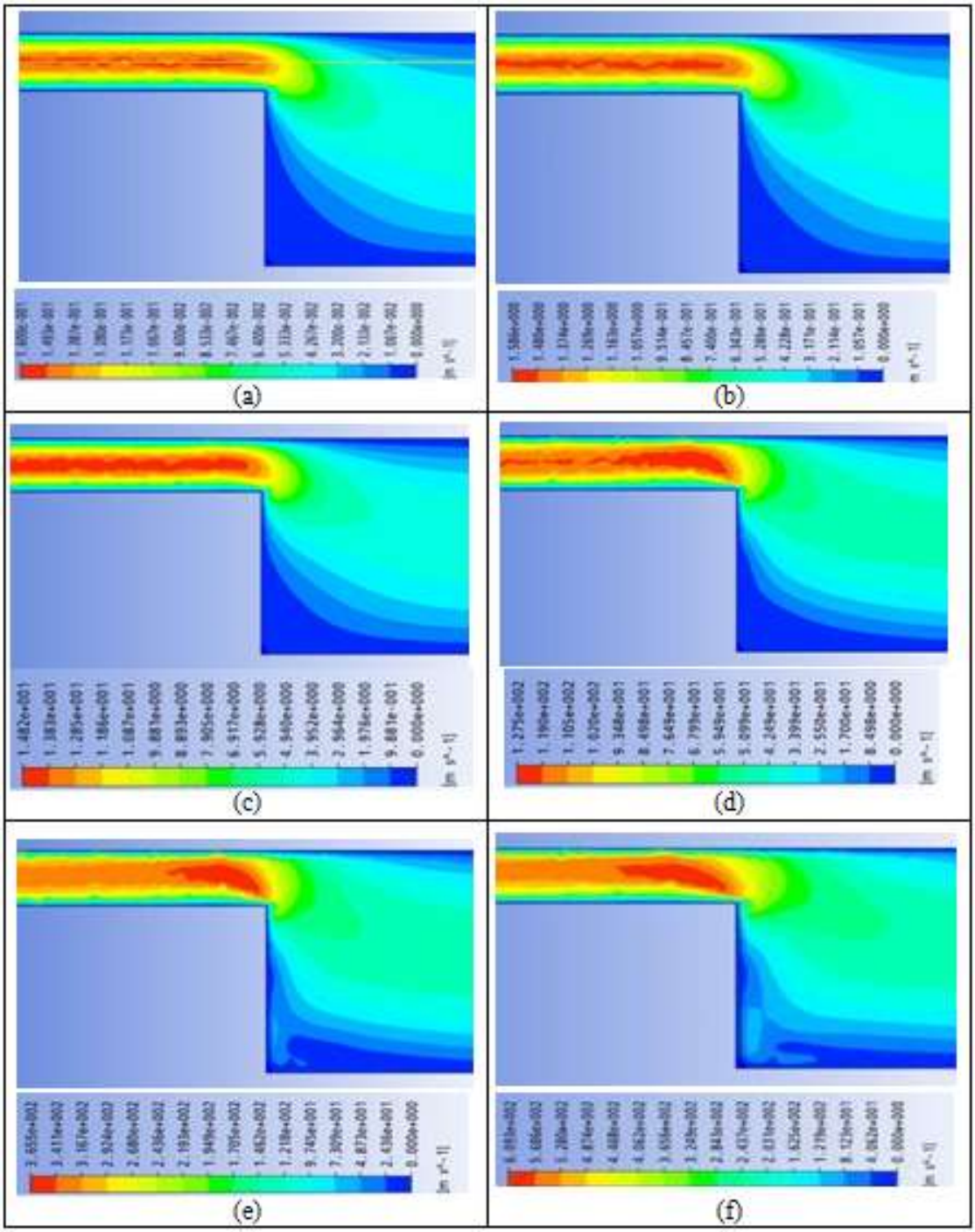

Fig. 6: Analysis velocity contour at 75% step with different Re (a) 0.1, (b) 1, (c) 10, (d) 100, (e) 300 and (f) 500

Conclusion:

The study on the laminar flow velocity profile over forward facing step microchannel has been presented. The effect of various Reynolds numbers and different step height has been investigated as well. The simulation results showed that fluid flow from a bigger section area to a narrower channel will increase the fluid velocity. In addition, Reynolds numbers parameter provides significant influence of the laminar flow in microfluidic channel.

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