Surface roughness influences to the behavior of flow inside microchannels

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Resumo: This work discusses influence of the surface roughness on the behavior of liquids flowing inside microchannels. By measuring the flow profile using the microPIV technique, the flow of water inside two rectangular microchannels of different wall roughness and in a circular smooth microchannel was studied. Comparisons were made between the experimental results, showing that a metrological approach concerning surface characteristics of microdevices is required to ensure reliability of the measurements for flow analyses in microfluidic processes.

Keywords: microfluidics, metrology, reliability, microPIV , microchannel roughness

1. INTRODUCTION

A reliable measurement for describing details of the fluid dynamics in microscale has been very challenger for scientists and for manufacturers of midrofluidic devices. In very tiny geometries, the flow behavior is not well represented by the equations and hypotheses which are commonly applied to flow in macrodomain, i.e., the Navier-Stokes equations, and boundary conditions strongly affects the performance and the flow process control. As metrological approach in microfluidic studies plays very important role for theoretical, experimental and computational developments devoted to provide reliability on achievements about such theme, technology advances in this field also has been driven by the need of ensuring confidence on the measurement for characterizing microflows. Besides, discussions, investigations and developments aiming metrological traceability chain establishment for flow measure in microscale have received attention from NMIs [1].

1.1 Aim of this work

When fluid flows in microscale, multiphysics effects [2] take place, and a process analyses can be misinterpreted. One parameter which clearly influences the microflow behavior is the roughness of the surface on which the flow is in contact. However, for flow inside microchannels it is very difficult to eliminate these influences, since the surface quality depends on the techniques for microchannel fabrication, as well as the material, and each technique has limitations. In the literature, it is known that surface effects in microflow is important, nevertheless, researchers do not concentrate discussions about that. Thus, aiming to contribute to call attention to the relevance of the metrological criteria in microflow characterization measurements, this work presents an introductory discussion about influences of the surface roughness of the wall channels for flow behavior in microscale. In this work, the flow of liquid occurs inside rectangular and circular channels where the resulting length scale characterizes the microfluidic behavior.

2. MATERIAL AND METHODS

The microflow measurements were carried out in three different straight channels: two of square cross section and one of circular cross section, as shown on table 1.

Table 1- Channels characteristics

Geometry	**Size**	**Material**
Circular	I.D: 1 mm L: 75 mm	borosilicate glass
Rectangular: One with polished side walls and one with unpolished side walls	H: 0.8 mm W: 0.8 mm L: 75 mm	borosilicate glass (side walls) and PET (bottom and ceiling)

The circular channel was a glass capillary (with smooth internal surface). The rectangular channels were constructed by carefully bonding two glass slides (microscope slides, plain) and two translucent and colorless polyethylene terephthalate (PET) strips. Care was taken to avoid the channel clogging with glue. The mean roughness of the polished (ground glass) side wall of one channel is around 0.8 µm. The unpolished side wall is bright and smooth (with roughness less than 0.05 µm), but it is slightly waviness.

The particle image velocimetry microscopy technique, microPIV [4], from Dantec Dynamics®, was employed to obtain the flow velocity field. A high-resolution CCD sensor (FlowSense 4M Mk2 with a resolution of 2048 x 2048 pixels) and a Nd: YAG double-pulsed laser light source, producing a short pulse of 5 ns of green light (532 nm), were adapted to the inverted microscope (Leica Microsystems®, model 090-135.003) to illuminate and visualize the flow using a 10x magnification lens. PMMA Rhodamine B-Particles of mean diameter 1 µm were seeded in the flow as tracers. For each liquid flowrate, 100 pairs of images were captured at a frequency of 7.4 Hz, with time between pairs of images varying between 500 µs and 20000 µs (according to the fluid flowrate). A syringe pump (Havard Apparatus® Pump 11 Elite) promoted the displacement of a 10 mL syringe containing the working fluid (deionized water and tracer particles) according to the set flowrate. In previous work the metrological reliability of this syringe pump was evaluated under the basis of totalized volume upon different liquid flowrate [3].

3. EXPERIMENTAL PROCEDURE

Each channel was connected to the syringe pump, separately, through a hose. Deionized water was seeded with PMMA Rhodamine B-Particles, and after setting the flowrate at the pump control panel, water was sent to the channel, and the resulting field of velocity was measured with the microPIV system. With this system, the center of the flow visualization window was placed at the middle length of the channels (L/2). The water flowrates in the experiments were the following:

Table 2- Water flowrate

Reference Flowrate [µL/min]		
Circular channel	Rectangular channel (polished walls)	Rectangular channel (unpolished walls)
50	50, 100, 200, 500	10, 50, 100, 200, 500

The flow velocity field was mapped after a mean of 100 pair of the flow images were compared. It is important highlight here that the flow field which is shown in the next section is related to a horizontal plan which is placed around the middle height of the channel. It is said "around" because when microchannels are studied with the use of the microPIV technique, the correct position of the plan of measurement cannot be determined with accuracy. This problem means a limitation in the microPIV technique use, and this lack shows a need of metrological investigation and the need of procedures and standards development for positioning the focused optical plan when aiming microflow dynamics analysis. It is a challenge. At Inmetro, this issue has received attention by the Fluid Dynamics Metrology Division.

4. RESULTS AND DISCUSSION

The pictures below show the velocity fields for minimum and maximum flowrates. The graphs were plotted using the same size and color scales in order to allow a quick comparison.

4.1. Water flowrate 50 µL/min

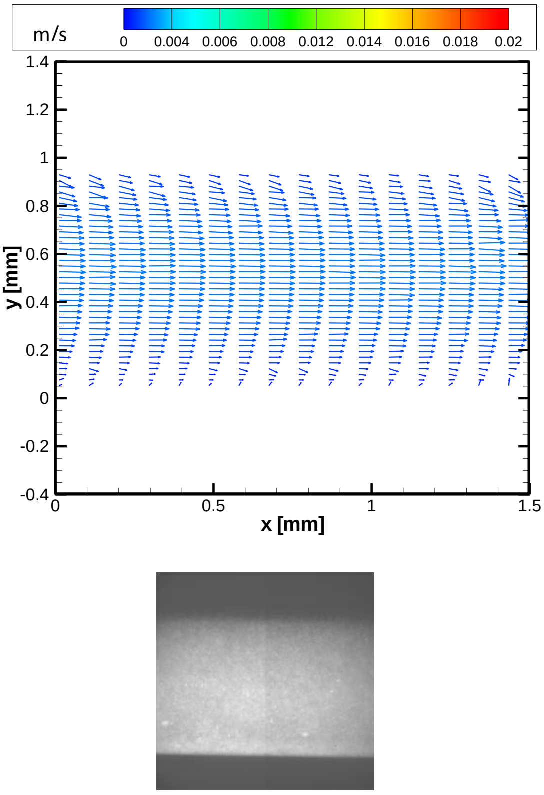

Figure 1- Circular channel: velocity field (above) and a frame of the flow (below)

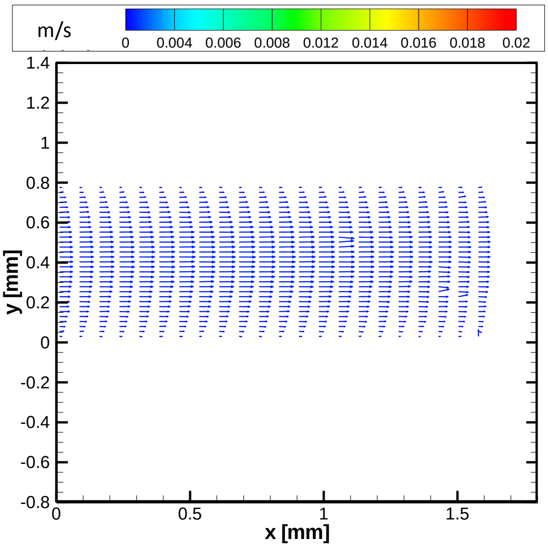

Figure 2- Rectangular channel (polished wall): velocity field

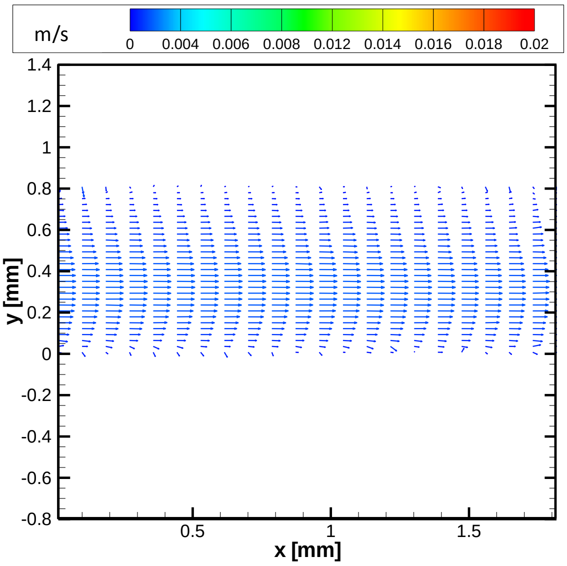

Figure 3-Rectangular channel (unpolished wall) velocity field

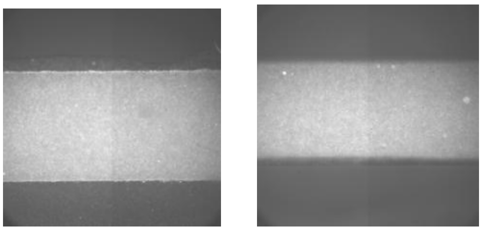

Figure 4- Frames of the flow in the rectangular channels: polished wall (left); unpolished wall (right)

4.2. Water flowrate 500 µL/min

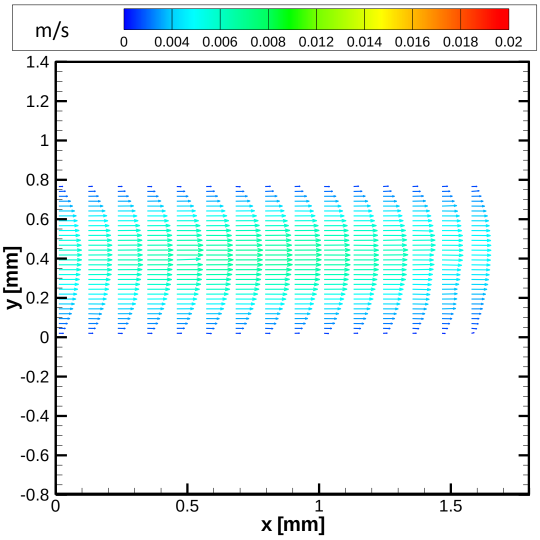

Figure 5-Rectangular channel (polished walls)

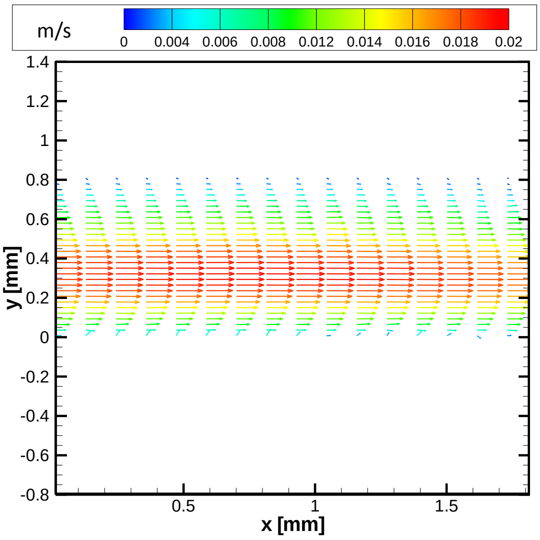

Figure 6-Rectangular channel (unpolished walls)

As can be seen in Figures 1 to 3, at very low flowrate the velocity field for the circular and rectangular channels are within the range near zero. Also, a similarity between the velocity field of the rectangular channels shows that, although there are differences between the mean size of the wall roughness of the channels, as the flow is very slow, the differences between the resulting shear rate are not significant. However, when the flowrate is increased, differences are perceived. Since the width of the channel is in microscale, when the side wall is rough the friction effects generated at the channel wall are propagated in considerable intensity to all main flow, when compared to the case of smooth wall under a same flowrate. As consequence, the longitudinal components of the velocity vector around the centerline of the channel become less than those when the wall is smooth.

Besides, an asymmetry of the flow field (Figures 3 and 6) was observed, and it can be due to the unpolished walls be slightly wavy, or even due to some irregularities which could have arisen during the process of channel construction.

Then, the results aforementioned show that a metrological approach considering the surface condition of the geometries where a microflow occurs has to be accounted in microflow analysis, since this can impact on the results of microfluidic processes. Here were shown the first results in this research line at Inmetro, and the investigations will be continued, including other fluids and discussions about influences due to microchannel fabrication techniques.

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