Micro-PIV characterization of laminar developed flows of Newtonian and non-Newtonian fluids in a slit channel

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1. Introduction and Objectives

The characterization of the flow in slit channels is relevant to attain efficient operation conditions in many separation processing equipments.

Spiral-wound membrane modules is a widely spread separation technology used in nanofiltration and reverse osmosis [1]. The hydrodynamics inside channels can be modeled by the flow inside slits. These modules are filled with spacers to enhance the mixing and to reduce polarization concentration. However this work studies the flow in an open channel to evaluate the feasibility of using micro-PIV to obtain velocity maps.

Conventional micro-PIV is a technique used since late 1990's to obtain velocity maps but it has been used mainly for micro-channels [2]. No previous works were found on the study of the flow in slits using this technique.

In a previous work the flow in this same slit model was characterized only in terms of global parameters, like the pressure drop and the visualization of the flow with dye [3].

2. Methodology

The laminar developed flows of newtonian liquids – water and water-glycerol(52%w/w) – and non-newtonian (pseudoplastic) liquid – water-glycerol(35%w/w)-xanthan gum (0.02%w/w) – are studied in a cell that models a slit channel with dimensions of 1.3×30×200 mm (Figure 1). Their top and lateral optical acesses permit the utilization of the micro-PIV technique to obtain velocity maps of the fluid flow.

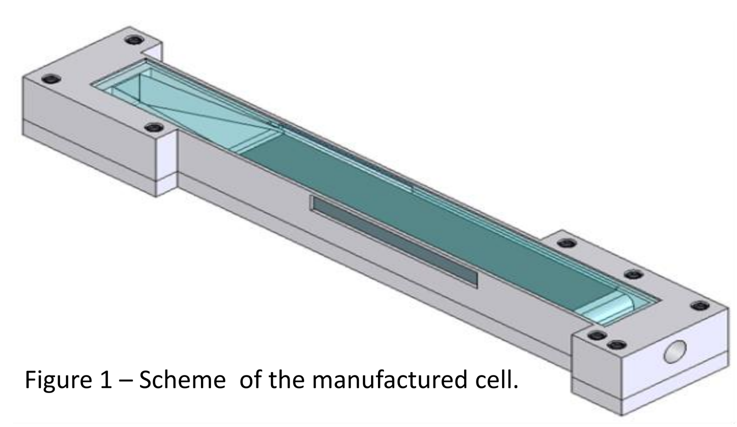

Figure 1 – Scheme of the manufactured cell.

The micro-PIV technique consists in determining the displacement of patterns of particles, seeded on the fluid, during a pre-defined time interval. In our work it is used a system that captures pairs of frames in a CCD camera and the fluorescent particles (1μm) are excited by a pulsed Nd:YAG laser (Figures 2 and 3).

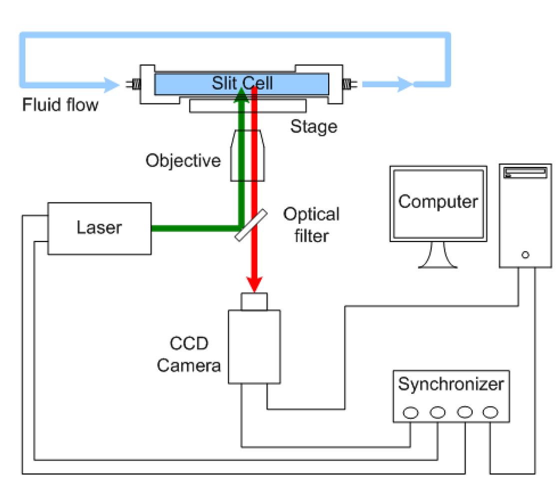

Figure 2 – Micro-PIV system.

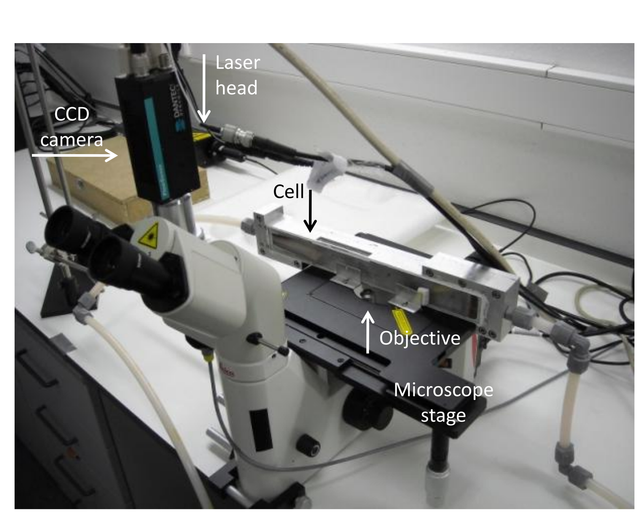

Figure 3 – Manufactured cell mounted on microscope stage.

Assuming the flow as steady Average Correlation algorithm is used to determine the velocity maps with a spacial resolution of 47.4×47.4μm^2 using a 10x lens (NA = 0.25). Obtaining velocity maps at several focal plane depths from the lateral window (Figure 4), in a region downstream enough from the entrance to ensure a developed flow, allows one to reconstruct the three dimensional velocity profile near the wall. Doing the same from the top window the two dimensional velocity profile at middle witdh of the channel is obtained.

The focal plane depth was determined using its dependence on the refractive index of the flowing fluids [4].

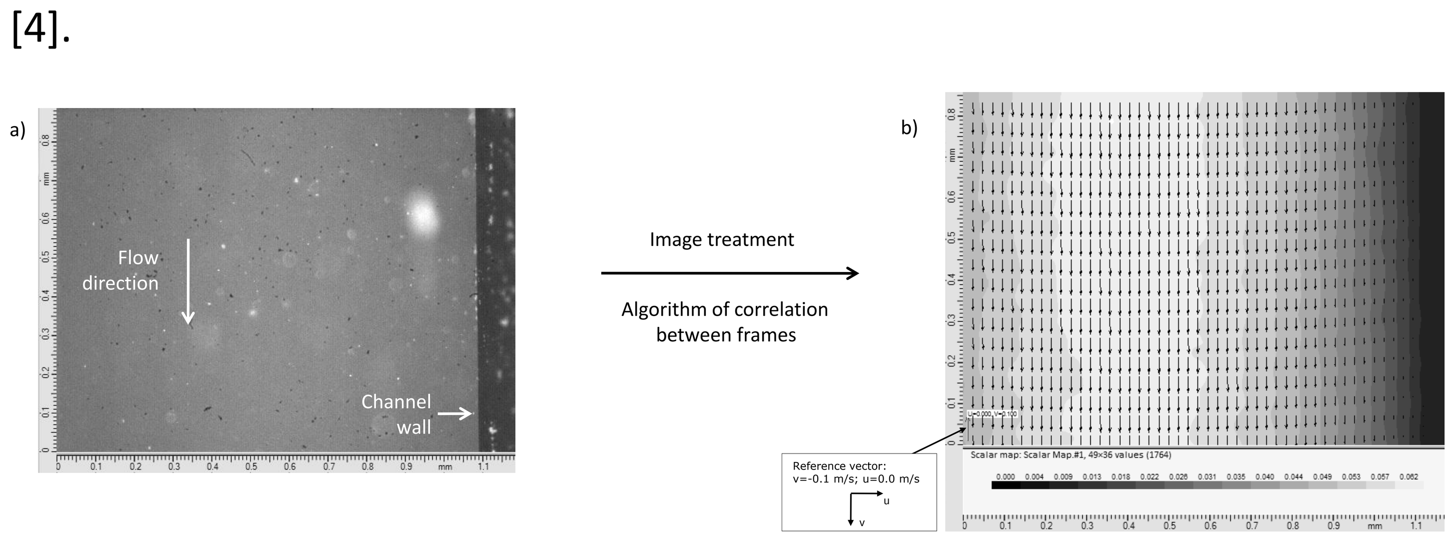

Figure 4 – a) real image of the flow in the slit channel; b) obtained velocity map (scale in m/s).

The experimental results of water and water-glycerol mixture can be compared with the velocity profiles calcuted using the analytical solution for developed flow of newtonian fluids in a rectangular open channel [5].

The viscosities of all fluids used are experimentaly determined with a cone-plate viscometer at constant temperature.

3. Results and Discussion

With the used experimental setup the velocity maps were determined up to a depth of 3 mm in the flows of water and water-glycerol mixture, and up to a depth of 1.5 mm in the flow of the water-glycerol-xanthan mixture.

The obtained two dimensional velocity profiles of the newtonian fluids are parabolic while the ones of the pseudoplastic fluid are slightly flattened in the central region of the channel, similarly to previous works [5,6], (Figure 5).

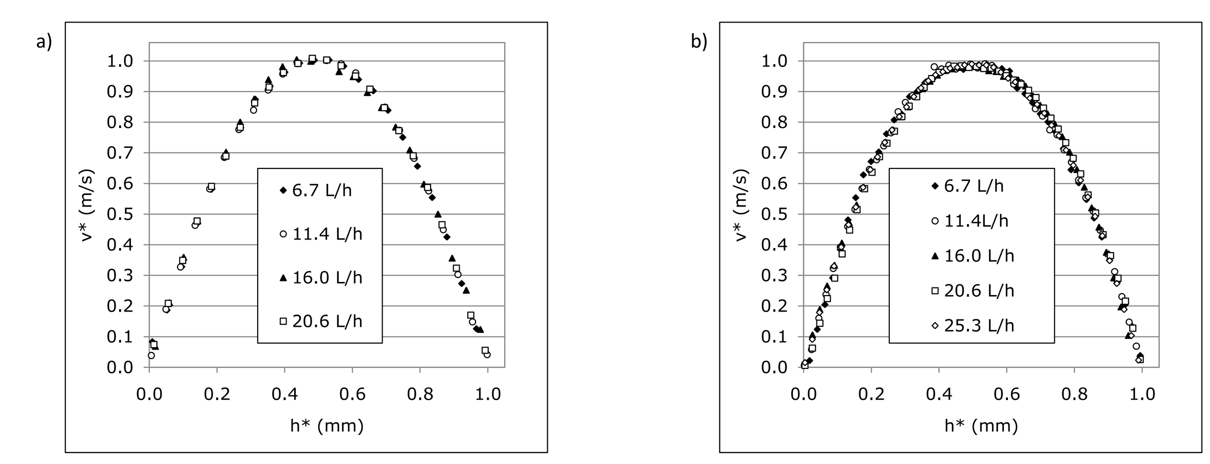

Figure 5 – Two dimensional profiles of dimensionless velocity, v*, versus dimensiolesss height, h* , at half witdh of the channel of the flows of: a) water-glycerol; b) water-glycerol-xanthan mixture, obtained from the top optical access.

In Figure 6 several velocity profiles which give an idea of the three dimensional velocity profile are shown.

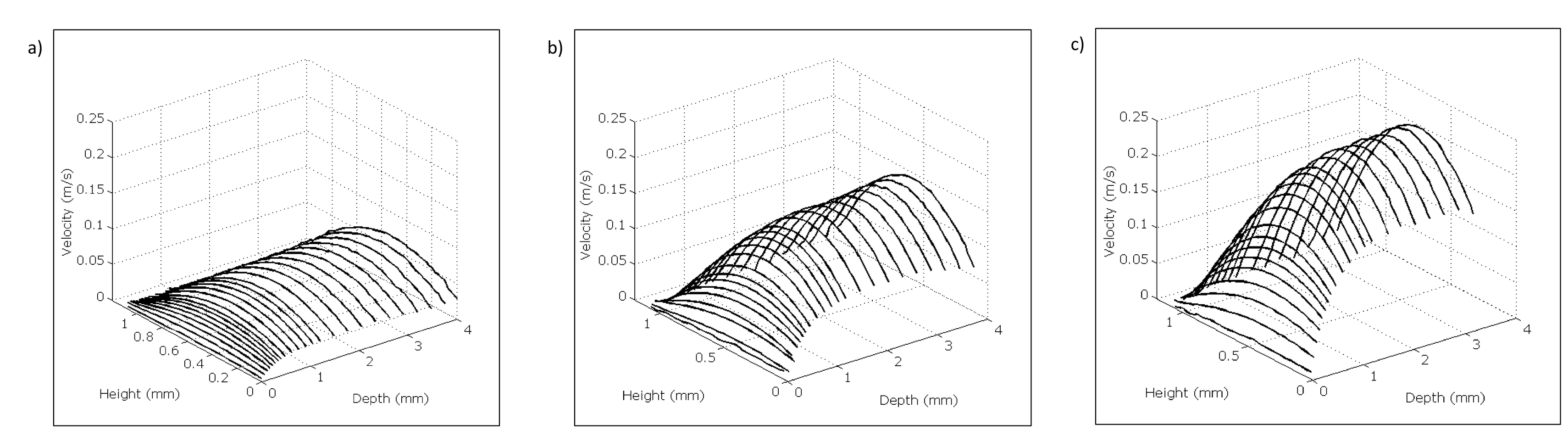

Figure 6 – Reconstructed three dimensional velocity profiles at half witdh of the channel of the flows of water-glycerol mixture for the flowrates: a) 6.7 L/h; b) 16.0 L/h; c) 25.3 L/h, obtained from the lateral optical access.

Despite deviations between experimental and analytical values near the wall, in the range of 10 to 15%, probably due to geometrical uncertainties of the channel cross-section, the results present good shape agreement particularly as far as the depth of velocity stabilization is concerned: between 1.5 and 2 mm (Figure 7).

The pseudoplastic behavior of the non-newtonian fluid (WG35X002) was determined (Figure 8) and it matches very well the one of the blood [7].

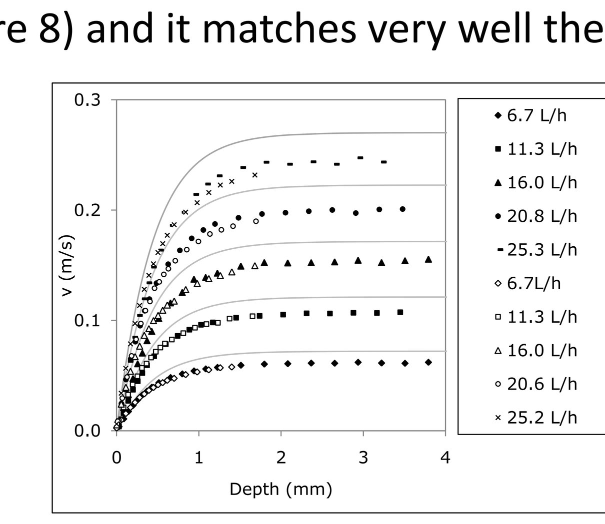

Figure 7 – Comparision of the experimental and analytical velocity profiles at the half height of the channel: closed symbols and -: WG52; open symbols and ×: WG35X002; grey lines: analytical solution.

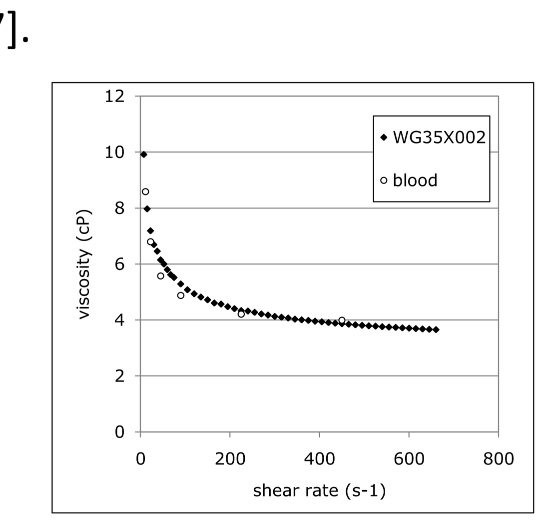

Figure 8 – Comparision of the viscosities of the used water-glycerol-xanthan mixture and blood.

4. Conclusions

The present work proves that it is possible to use the micro-PIV technique to obtain velocity maps of the flow of liquids in slits.

As expected the 2D velocity profiles of newtonian fluids are parabolic while velocity profiles of the non-newtonian fluid are slightly flattened in the central region of the channel.

The used non-newtonian fluid has a viscosity behavior close to that of the blood.

The comparision of experimental results with the analytical solutions for laminar developed flows in rectangular slits are very encouraging and shows that the velocity stabilizes at depths near 2 mm from the lateral wall.

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