Influence of illumination and tracers on Particle Image Velocimetry measurements on open flow channels

Influența iluminării și a trasoarelor asupra măsurătorilor de velocimetrie a imaginii particulelor pe canalele de curgere deschise

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DOI: 10.37789/rjce.2021.12.4.1

Abstract. *Within the study of free surface flows, measurements in the vertical planes of the flow are desired. Using Particle Image Velocimetry, usually measurements are performed with the laser sheet through the bottom of the channel in order to avoid the optical perturbations on the laser light sheet, generating light scattering and measurement artefacts. There are however a number of cases where this is not possible since the transparence of the bottom cannot be ensured. In the present study we wanted to check the influence of the illumination on the velocity fields distribution, through the bottom of the channel or through the free surface, on a very simple flow on a plane plate placed on the bottom of a circular channel. We also checked the influence on using conventional silver hollow glass spheres and fluorescent particles.*
The results allowed us to conclude that in the cases where the study is focused on the boundary layer close to the solid surface and the observed perturbations of the free surface are not important, top illumination of the open channel might be considered as an option if perturbations of the free surface are not observed.

Key words: *PIV, free surface flows, optical techniques*

1. Introduction

Particle Image Velocimetry (PIV) represents a reference tool for the analysis of a wide range of flows. A wide range of three-dimensional applications, including free surface flows, can be found in the recent literature.

The application of PIV for experimental studies in open-channel flows can be challenging due to the presence of strong velocity gradients and the inclusion of moving interfaces in the captured images. This way, understanding the performance

and limitations of the PIV technique under these conditions is critical for optimizing experimental parameters and robust interpretation of data. The accuracy and precision of PIV measurements is highly affected by the quality of the captured images which in its turn depends on several conditions that should be accomplished by the channel and the fluid. Thus, besides complying with the conditions imposed by ensuring geometrical similitude, the experimental models for internal flows must comply with two specific conditions: the ability of the tracer particles to follow the instantaneous motion of the continuous phase and to scatter light on one hand and the transparence and the refraction index of the channel.

When working with free surface flows, usually measurements in the vertical planes of the flow are desired. In this case it is somehow acknowledged as common sense that the laser sheet would pass through the bottom of the channel. Indeed, the presence of the strongly perturbed free surface would act inducing optical perturbations on the laser light sheet, generating parasite scattering as well. There are however cases where this is not possible since the transparence of the bottom cannot be ensured.

Studies of our colleagues [1, 2] regarded for instance the flow characteristics of artificially roughened channels simulating deposits on sewer pipes. Other studies where interested on the flow around bodies immersed near the free surface of the channel [3].

In these two examples is impossible to insure illumination through the bottom of the channel. During an experimental campaign related to an extension of the analysis performed in [1, 2], we wanted to check the influence of the illumination on the velocity fields distribution, through the bottom of the channel or through the free surface, on a very simple flow on a plane plate placed on the bottom of a circular channel (Fig. 1). We also checked at the occasion the influence on using conventional silver hollow glass spheres and fluorescent particles.

2. Methodology

In this study it has been considered a system which generates a free surface flow in a circular sewage pipe, with deposit material at the bottom. The interior pipe diameter is D_i=144 mm, pipe length is 3,9 m made of poly acrylate. The experimental setup is presented in Figure 1. The water is pumped from the tank (1) towards the tank (5). This one is a free surface tank and from here we obtain a free surface flow through the main poly acrylate pipe from the tank (5) towards the tank (1). The flow rate is determined with an ultrasonic flow meter (6) and it may be varied using a regulation valve. A plane plate was fixed on the bottom of the channel to simulate the deposits on the bottom of the pipe.

In this study, we have employed a Dantec Particle Image Velocimetry (PIV) system for the velocity field measurements. This system is composed of one high sensitivity Flow Sense EO camera of $4x10^6$ pixels resolution and of a Dual Power 200 mJ laser having the wavelength of 532 nm. The acquisition frequency of the PIV

system was 5 Hz. The image calibration gave a spatial resolution of 160 µm per pixel, which corresponds to a 270 x 270 mm² field of view.

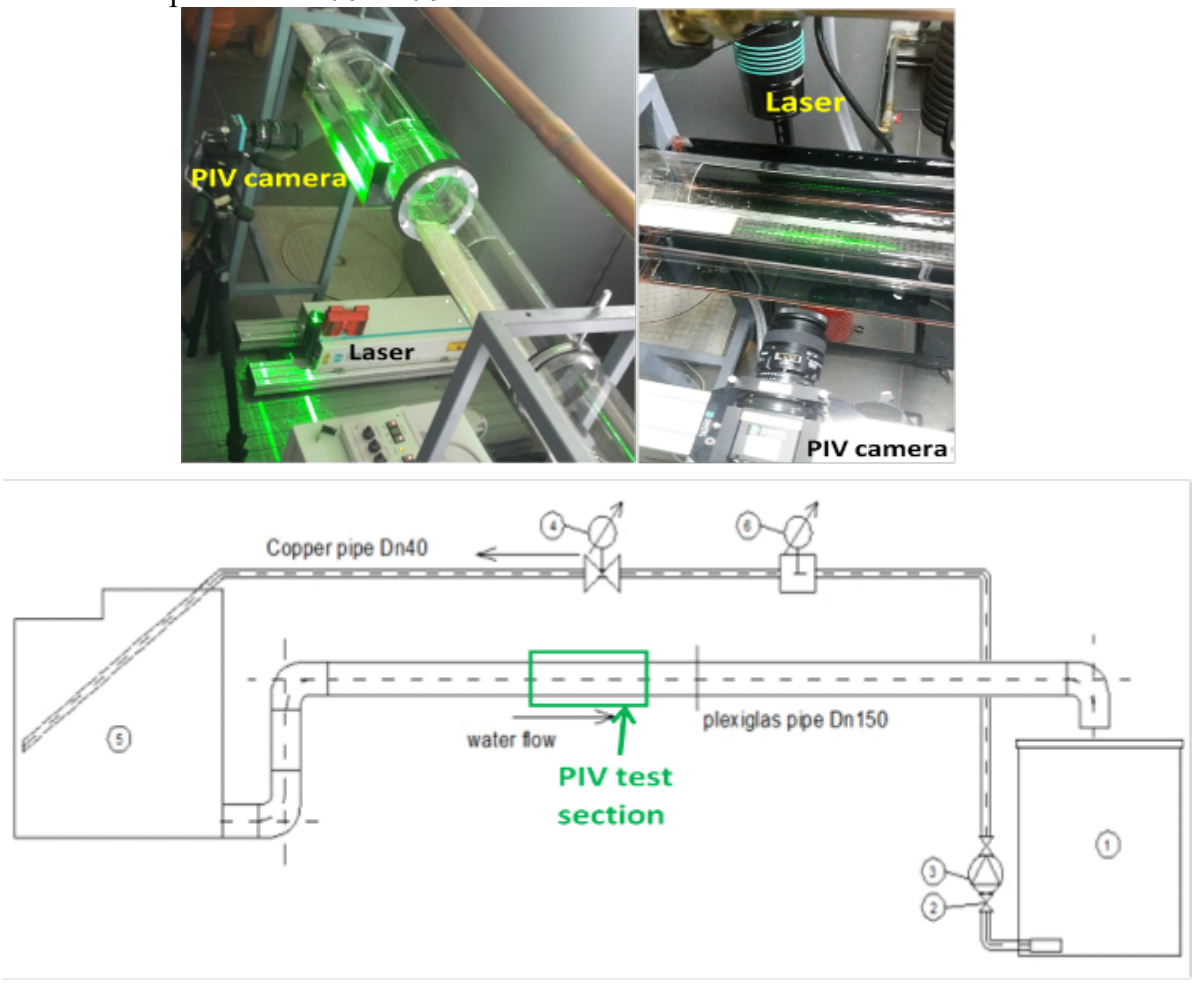

Fig. 1 Experimental set-up using the laser illumination from the bottom of the channel and from the top of the channel through the free surface

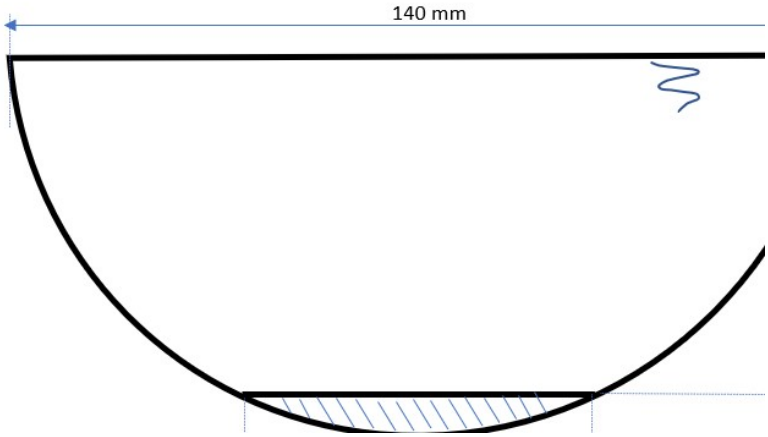

Fig. 2 Plate plane on the bottom of the channel simulating deposits

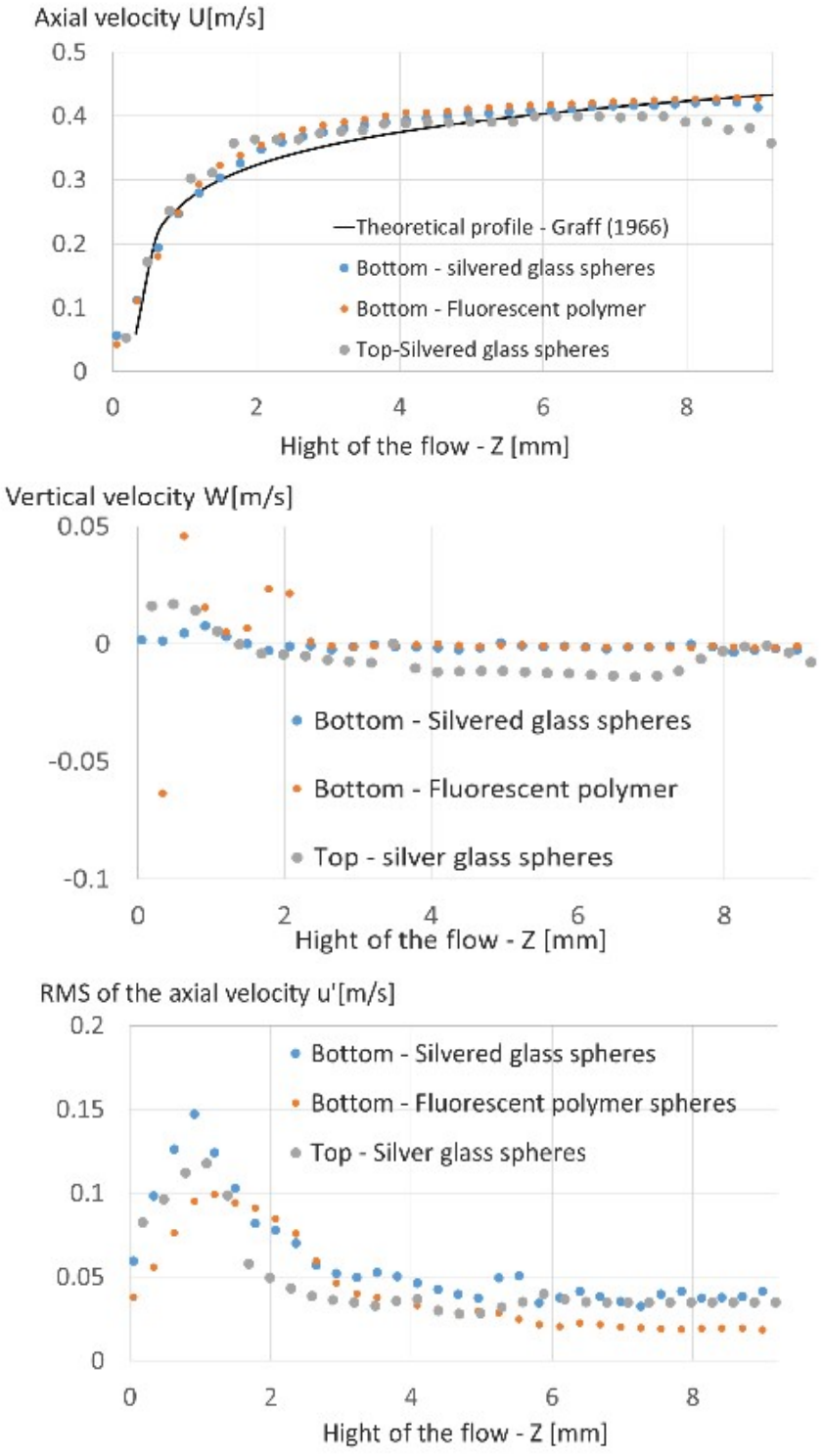

Fig. 3 Comparison of the axial and vertical velocity profiles and of the RMS of the axial velocity for one of the studied flow rates corresponding to a free stream velocity of 0.3m/s

As we wanted to check the influence of the position of the laser plane on the velocity fields distribution, passing through the bottom of the channel or through the free surface, we chose to use this on a very simple flow on the plane plate placed on the bottom of a circular channel (Fig. 1). We also wanted to compare the influence on using conventional silver hollow glass spheres and fluorescent particles.

To this end two types of tracer particles were compared along with two laser illumination strategies: a) the laser plane was incident from the bottom of the channel and silvered glass micro-spheres were used, b) the laser plane was incident from the bottom of the channel and fluorescent polymer micro-spheres were used, c) the laser plane was incident from the top of the channel and silvered glass micro-spheres were used.

3. Results

The axial velocity profiles presented in Fig. 3 display differences only next to the free surface. We observed this phenomenon for several flow rates corresponding to free stream velocities of respectively: 0.3m/s, 0.5m/s, 0.6m/s, 0.7m/s. The surface velocity seems to display slight smaller values for the lowest flowrates in the case with top illumination. This gap is much reduced for higher flowrates.

Using the empirical profile proposed by Graf [4] one could observe that the top illumination cases are display closer values to the ones preconized by the theory. It is important to note here that we couldn't observe, with the naked eye, perturbations of the free surface of the flow.

Concerning the vertical velocities and the RMS values of the velocity components, values are quite different for the different seedings as well as for the two positions of the illuminations. However, these differences fall into the measurement method incertitude.

We have to note also that the polymer fluorescent particles have a slightly higher density than the one of the water, while the hollow silvered glass spheres have a slightly lower density and this could also influence the velocity profile distribution observed in the previous figures.

Conclusions

Within the study of free surface flows, measurements in the vertical planes of the flow are desired. Using Particle Image Velocimetry, usually measurements are performed with the laser sheet through the bottom of the channel in order to avoid the optical perturbations on the laser light sheet, generating light scattering and measurement artefacts. There are however a number of cases where this is not possible since the transparence of the bottom cannot be ensured. In the present study we wanted to check the influence of the illumination on the velocity fields distribution, through the bottom of the channel or through the free surface, on a very simple flow on a plane

plate placed on the bottom of a circular channel. We also checked the influence on using conventional silver hollow glass spheres and fluorescent particles.

The results allowed us to conclude that in the cases where the study is focused on the boundary layer close to the solid surface and the observed perturbations of the free surface are not important, top illumination of the open channel might be considered as an option if perturbations of the free surface are not observed.

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