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EXPERIMENTAL STUDY ON ROD-LIKE PARTICLES SUSPENSIONS IN A BACKWARD-FACING STEP CHANNEL FLOW

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ABSTRACT

A backward-facing step channel flow at Reynolds number 15000 laden with rod-like particles at different volume concentrations is investigated by means of Particle Image Velocimetry. High spatial resolution allows for particles orientation detection. Interactions among flow features and fiber orientation are analysed and discussed.

INTRODUCTION

The understanding of turbulent two-phase flows in which a solid phase is dispersed into a fluid is of great importance in many industrial applications such as cyclone separators, post-combustor devices and chemical reactors. Many efforts have been given in this direction and the majority of investigations can be divided into two main frameworks: the determination of the dispersed phase distribution and concentration induced by the specific flow features and the modification of the fluid phase statistics due to the presence of a solid phase. The former is of particular interest for industrial applications where particle concentration within the flow represents a key factor, such as combustion devices, and has been the object of several works (Eaton and Fessler (1994) among others). The latter, specifically the turbulent modulation induced by the dispersed phase in the flow, has also been the subject of many papers (Parthasarathy and Faeth (1990), Fessler and Eaton (1999) among others) and a comprehensive review is given in Balachandar and Eaton (2010).

A historically important class of turbulent flow is represented by the backward-facing step in a channel, which in addition to applications in several areas of engineering can also provide a convenient and geometrically simple test model for turbulent flows with high shear.

Although in most investigations spherical particles are used as dispersed phase, in many applications, the dispersed phase cannot be deemed as spherical (pulp production, paper manufacturing, cloud formation) and rod-like particles, characterized by high (>5) geometrical aspect ratio, provide a much better approximation of the effective dispersed phase (i.e. wood fibres or ice crystals). Although there are works on the effect of fiber-suspensions in turbulent flows (Krochak et al (2008), Parsa et al (2011) and Parsheh et al (2005), Marchioli et al (2010)), yet, there is a lack of studies on the interactions between rod-like particles and carrier fluid in turbulent shear flows.

To this aim, in this work a backward facing step flow laden with rod-like particles is investigated by means of Particle Image Velocimetry (PIV) in order to obtain simultaneous particle and fluid velocity fields and shed light on the interactions between the two phases.

EXPERIMENTAL SET UP

The experimental apparatus, depicted in Figure 1, consists of a backward facing step channel 100cm long and 20cm wide, featuring a step height of H=1cm and an expansion ratio of 1.5. Tests were carried out with a Reynolds number of 15000, based on inlet maximum velocity and step height. For this geometry and Reynolds number existing data can be used for comparison. Nylon fibers of 20μm diameter and length l=300μm were used as a dispersed phase and two different volume fraction concentrations, namely Cv1=0.02% and Cv2=0.05% were tested. As flow seeding neutrally buoyant 10μm diameter hollow glass spheres were used and tests with no fibers were carried out as a reference. Measurements were performed upstream of the step (about -10 H from the step) and downstream on an area of approximately 3.5 H, thus allowing high spatial resolution (13μm per pixel). From images containing both seeding particles and fibers (Figure 2), by using the post-processing phase discrimination technique detailed in Dearing et al. (2013), it was possible to attain simultaneous data of carrier and dispersed phase, making it also possible to derive fiber orientation. PIV computations were performed by means of LaVision Gmbh DaVis commercial software, using final step window size of 32x32 pixels with 50% overlap, corresponding to grid spacing 0.016H.

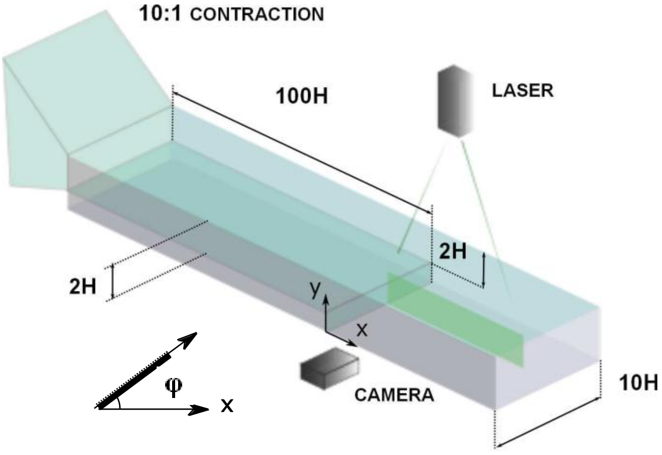

Figure 1:Experimental apparatus

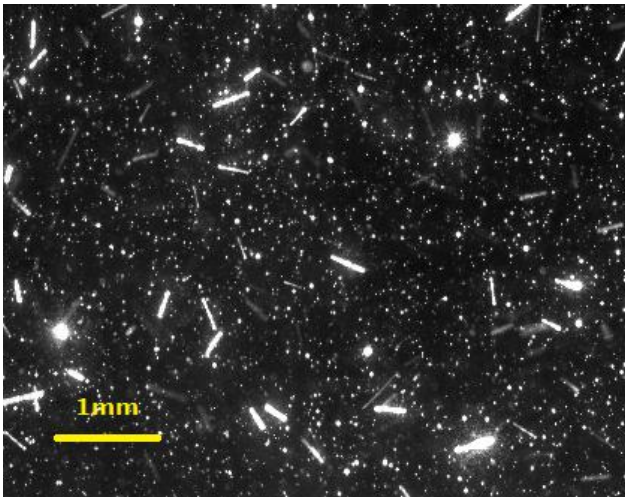

Figure 2:Sample seeding and fibers image

RESULTS

Mean velocity and turbulence intensity data for the unladen reference condition were compared to Particle Tracking Velocimetry data from Kasagi et al. (1993) obtained at Reynolds number 5540. The agreement with these data is good either for the mean velocity and the second-order statistical moments.

Mean axial velocity data of unladen and fiber-laden flow at the two different mass concentrations are compared in Figure 3 upstream and downstream of the step. All these values appear almost unaffected by the injection of the dispersed phase thus confirming the findings reported in Fessler and Eaton (1999) for spherical particles. On the other hand, RMS axial velocities, show an increase in turbulence intensity just after the step (x/H=0.2 and x/H=1, y/H>0.8) for increasing fiber concentration, as shown in Figure 4. As the distance from the step increases, turbulence increase is no more noticeable and already at x/H=6, i.e. approximately at the flow reattachment point, the RMS data do not show relevant differences with the unladen condition as also reported by Fessler and Eaton (1999). Fiber orientation data, based on the orientation angle φ between the horizontal x axis and the projection of the fiber on the x-y plane, as defined in Figure 1, are provided in Figure 5 (angles are given in degrees) for the acquisitions with fiber concentration equal to Cv2, made upstream of the step (x/H= -10). This analysis is performed to investigate if the flow field in the wall region is limiting for possible fiber orientations.

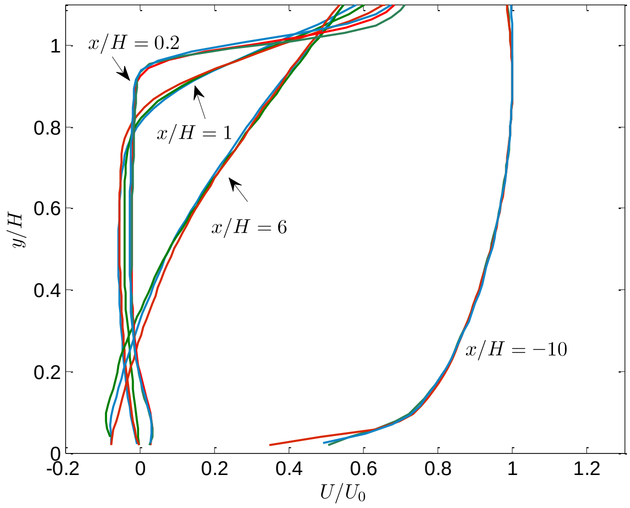

Figure 3:Mean axial velocity profiles of the fluid. Blue=unladen, green=Cv1, red=Cv2

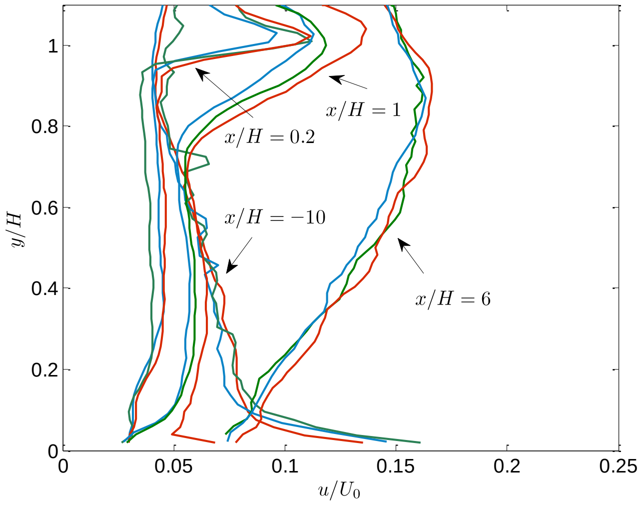

Figure 4:RMS axial profiles. Blue=unladen, green=Cv1, red=Cv2

The fiber mean orientation angle is slightly positive (φ ≈10°÷15°) in the wall region and then vanishes towards the center of the channel, with a change of sign moving towards the upper wall (not shown in the picture). Therefore, it seems that close to the wall fibers tend to align to the velocity gradient direction, thus pointing away from the wall, whereas towards the center of the channel they are mostly aligned with the mean flow.

The RMS of the orientation angle φ may is a measure of the oscillations of fibers while moving with the fluid flow. In Figure 6, this quantity is shown upstream of the step for fiber concentration equal to Cv2. Close to the wall, the fluctuations of fiber orientations are limited thus indicating that they are mostly oriented around the mean value (given in Figure 5). The amplitude of these fluctuations largely increases when moving towards the channel centerline.

The mean and RMS values of the fiber orientation angle are computed also for the region downstream of the step and are shown in Figures 7 and 8, again for the largest fiber concentration Cv2. This region exhibits strong velocity gradients (as shown in Figure 3) so that it should have relevant effects on fibers orientation. From Figure 7, the mean orientation is slightly positive in the upper part of the imaged field in agreement with data taken upstream of the step (Figure 5), whereas in the recirculation region there are mostly negative angles.

On the other hand, In Figure 8, the RMS value of fiber orientation is quite small at the inlet section just behind the step, in agreement with the results upstream (Figure 6), while increasing largely in the recirculation region. As measured upstream of the step, in regions where there is a large velocity gradient, as in the shear layer and close to the bottom wall, the fibers orientate along the gradient direction with also small fluctuations around the mean. On the other hand, in those regions where the gradient is small, as in the recirculation region, they align with the mean flow with quite high changes in this orientation.

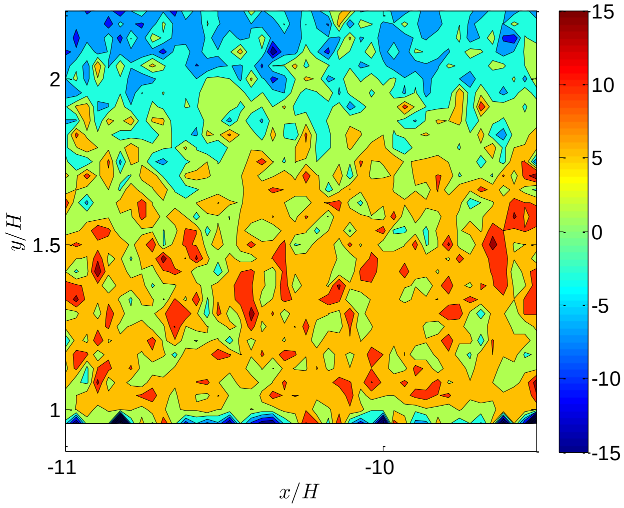

Figure 5: Mean fiber orientation at x/H=-10

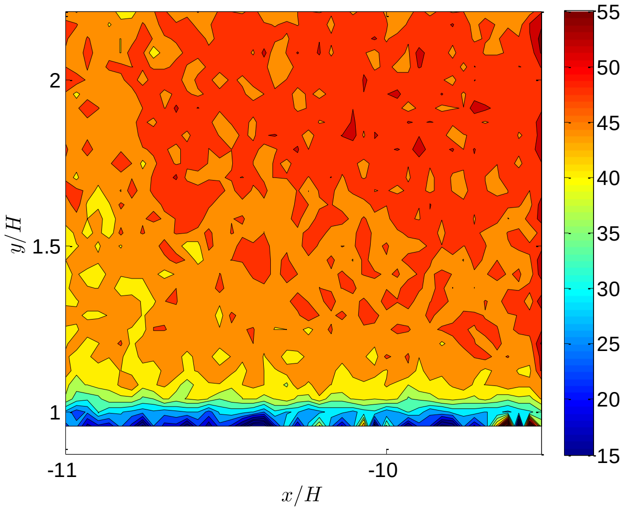

Figure 6: RMS of fiber orientation at x/H=-10.

REMARKS AND CONCLUSION

To better point out the relation among the fiber orientation and large angles of the mean velocity gradient, the latter is computed upstream and downstream of the step and presented in Figures 9 and 10 (the mean angles have the same reference of φ and it is measured in degrees). Upstream of the step, at the wall, the angles of the velocity gradient are around 10°÷20°, so very close to the measured fiber orientation given in Figure 5, while being very large towards the centerline. Downstream of the step, the mean velocity gradient is very high just after the step (so that the angle is close to 0), thus in agreement with fiber orientation. In the recirculation region the gradient is rather small and the angles close to 90°, and this is just the region where the fiber orientation is no more linked to the velocity gradient being mostly aligned with the mean flow. An attempt to relate the mean fiber orientations and fluctuations with RMS velocity fields reveal that the highest the former the lowest the latter as can be retrieved by comparing Figures 4 to Figures 6 and 8.

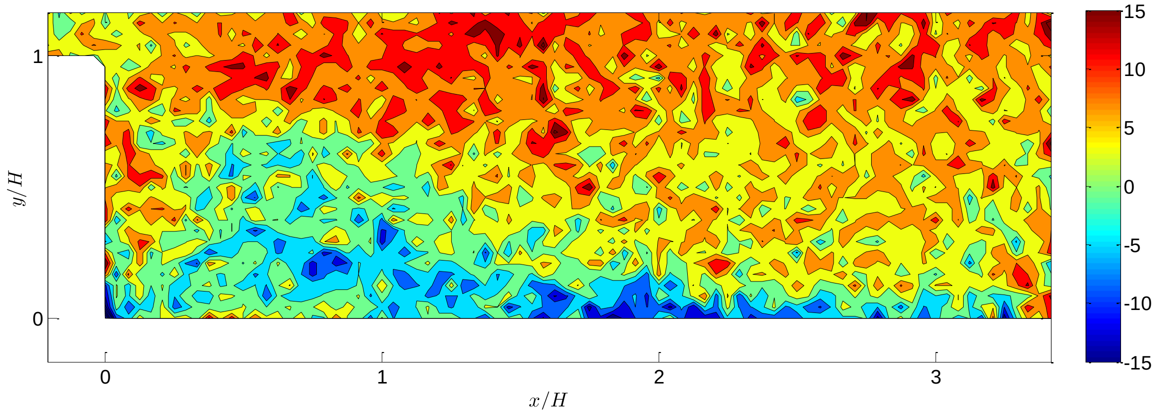

Figure 7: Mean Fiber orientation downstream of the step for C=Cv2

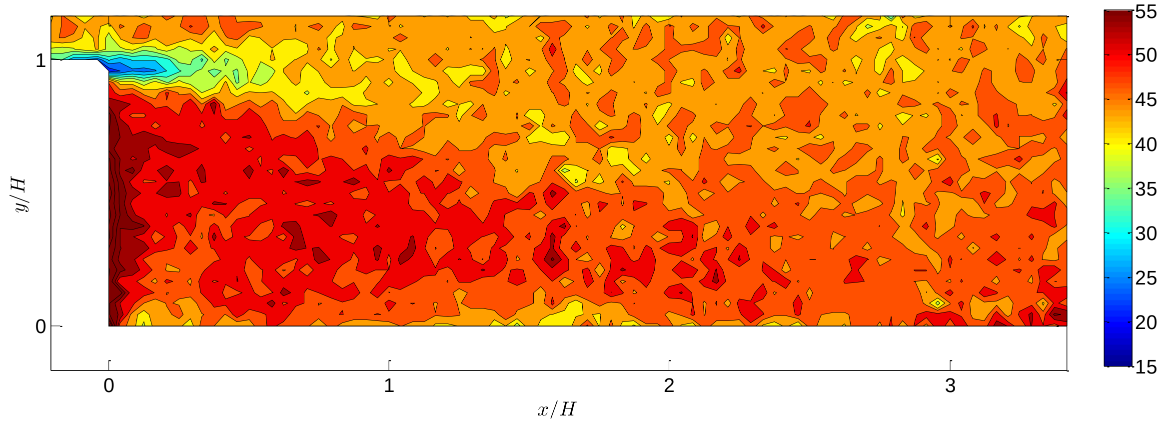

Figure 8: RMS of fiber orientation downstream oft he step for C=Cv2

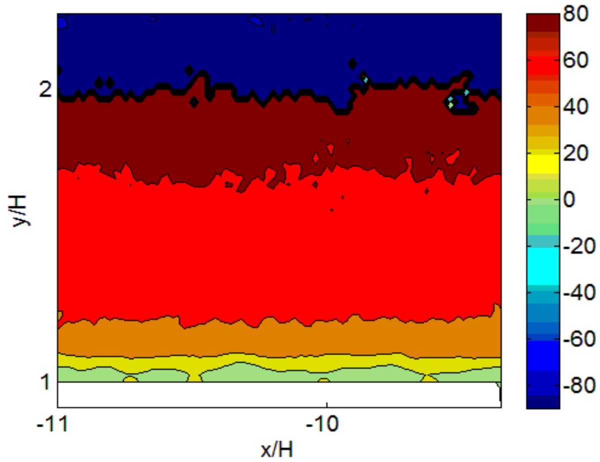

Figure 9: Mean velocity gradient angle at x/H=-10

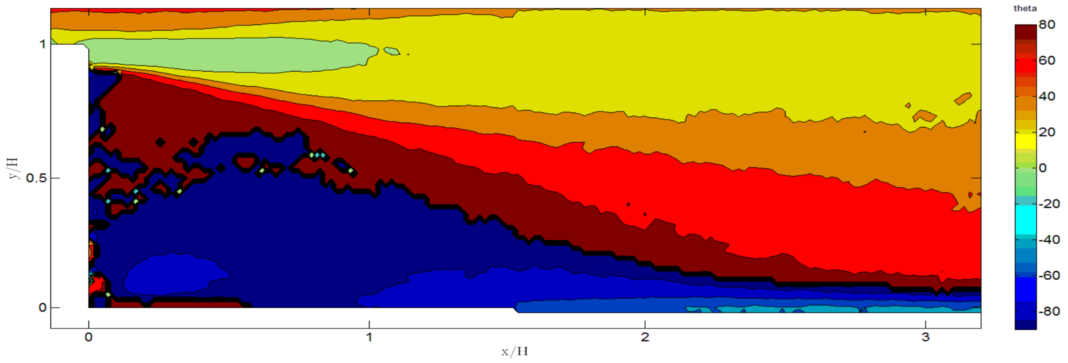

Figure 10: Mean velocity gradient angle downstream of the step

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