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PIV with volume lighting in a narrow cell: An efficient method to measure large velocity fields of rapidly varying flows

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ABSTRACT

In this work we test a methodology for PIV measurements when a large field of view is required in planar confined geometries. Using a depth of field larger than the channel width, we intend to measure the in-plane variations of the velocity of the fluid averaged through the width of the channel, and we examine in which operating conditions this becomes possible. Measurements of the flow through a narrow channel by PIV are challenging because of the strong velocity gradients that develop between the walls. In particular, all techniques that use small particles as tracers have to deal with the possible migration of the tracers in the direction perpendicular to the walls. Among the complex mechanisms for migration, we focus on the so called Segré–Silberberg effect which can lead to transverse migration of neutrally buoyant tracers of finite size. We report experimental PIV measurements in a Hele-Shaw cell of 1 mm gap, which have been carried out by using neutrally buoyant tracers of size around 10 μm. By considering steady flows, we have observed, in particular flow regimes, the effect of an accumulation of the tracers at a certain distance to the wall due to the so called Segré–Silberberg effect. The particle migration is expected to occur at any Reynolds numbers but the migration velocity depends on the Reynolds number. A significant migration therefore takes place each time the observation duration is large enough compared to the migration time. For a given observation duration, the tracers remain uniformly distributed at low Reynolds numbers whereas they all accumulate at the equilibrium position at large ones. When using volume lighting, the PIV algorithm provides the average velocity of the flow through the gap at low Reynolds number, while it leads to the velocity of the flow at the equilibrium position of the tracers at large Reynolds numbers. By considering unsteady flows, we have observed that the migration does not occur if the timescale of flow variation is short compared to the time required for the parabolic flow to develop across the gap. In this case, there is no transverse velocity gradient and the PIV algorithm provides the fluid velocity. Altogether, these results allow us to propose guidelines for the interpretation of PIV measurements in confined flow, which are based on the theoretical predictions of the tracer migration derived by Asmolov [1].

1. Introduction

With the recent development of micro-reactor engineering, the experimental study of transport and mixing phenomena in narrow channels is a new technical challenge [2,3]. Conventional PIV investigations use light sheet illumination ([4–6] in microchannel). For narrow channels however, the lack of optical access leads to front illumination (or volume illumination) of the flow [7,8]. Using this technique, all tracers distributed over the channel width are lighted. There are two ways of filming these seeding particles with the aim of performing PIV measurements. One consists in using camera optics with a depth of field that is small compared to the channel thickness; in that way the optical acquisition system must be adjusted to detect only the tracers located at a given distance from the walls [7,9]. The drawbacks of this method are its limitation to small measurement windows and a possible lack of tracers in the measuring plane. A more convenient solution is to use camera optics with a depth of field larger than the channel width. In this case, all the tracers laying in the field of view of the camera are well-focused and contribute to the velocity measurement [8]. Two other difficulties however arise, which have to be considered to make sure that the PIV measurements are relevant. The first concerns the PIV algorithm: while the fluid velocity ranges from zero at the wall to the maximum velocity at the middle of the channel width, velocity gradients at the scale of the PIV interrogation domain may decrease the amplitude of the displacement correlation peak and enlarge its width, reducing its detectability and

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