CHARACTERIZATION OF ADVECTIVE MICRO-SCALE MIXING IN 3D BY MEANS OF A STEREOSCOPIC PARTICLE IMAGING SYSTEM

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ABSTRACT

In this paper we present a 3D mixing characterization method based on stereoscopic imaging of micro-particles instead of dyes. With this approach the mixing structures do not “smear out” due to Brownian motion of a dye. The discontinuous tracer particle distribution increases the penetration depth of the optical system and it allows the undisturbed observation of regions deep in the microchannel.

For the mixing characterization measurement one of the two inflows of a micromixer is seeded with particles with a diffusion length of order 10 nm, while the second inflow remains unmarked. The position of the tracer particles is then imaged by means of stereoscopic microscopy. We currently reach a resolution in all three spatial directions that is better than 4 µm.

KEYWORDS: Mixing, 3D, stereoscopic imaging, diffusion

INTRODUCTION

While diffusion is the dominating effect in microscale mixing, diffusion indeed limits the investigation of advective mixing at microscale. All conventional mixing characterization methods suffer from this limitation. Typically micromixers are characterized based on integral measurements such as volume flow rate, pressure drop or global mixing measurements [1], as well as two-dimensional dye [2] and reaction visualizations [3]. Three-dimensional concentration distribution measurements by [4,5] scan the intensity of a fluorescence dye added to one of the mixing species with a confocal laser scanning microscopy (CLSM). From the CLSM data they determine the mixing quality and the specific contact area between the species. The spatial resolution of the CLSM visualization method is limited by the diffusion of the dye. By replacing the dye with nanoparticles, which have a much lower diffusion coefficient and as a consequence a smaller Péclet number the diffusion of the marker is reduced and higher resolution is achieved.

EXPERIMENTAL

For the mixing characterization measurement one of the two inflows of a micromixer is seeded with neutrally-buoyant, fluorescent nanoparticles, while the second inflow remains unmarked as shown in Fig. 1. The 800 nm-diameter particles have a diffusion length of order 10 nm. Thus diffusion does not influence the resolution of the measurement. The position of the tracer particles is then imaged by means of stereoscopic microscopy. For a precise determination of the particle position in 3D-space the stereo-microscope is self-calibrated [6,7].
Figure 1. Experimental setup (left) for the mixing characterization by means of stereoscopic particle imaging (not to scale). Two cameras are attached to a stereomicroscope and they observe the flow pattern in the micro-fluidic T-mixer. On the right the principle of 3D particle reconstruction is shown.

A T-shaped micromixer produced by DRIE with a rectangular cross-section and smooth walls serves as reference experiment. The inflow is from the two branches of the T-mixer with only one inflow seeded. At Reynolds number Re>140 the two stationary laminar inflows form a stable three-dimensional vortex pattern.

Figure 2. T-mixer geometry (left) with measurement region (orange) and result of a 3D particle imaging measurement. Shown is the distribution of the liquid originating from one inflow. Inflows are from top left (seeded), top right (unseeded and therefore not visible), outflow is to the bottom.
RESULTS AND DISCUSSION

Fig. 2 shows the results of the 3D mixing characterization measurement. The redistribution by advection of the fluid originating from the left inflow is represented color-coded in green. The intensity of the green indicates the concentration. The blue region inside the T-shaped micromixer indicate regions where no tracer particles have been located corresponding to the unseeded liquid originating from the right inlet. Filaments of 4 µm width could be resolved. In the left half of the outflow channel a stable vortex structure is visualized. The same structure appears with less contrast on the right in opposite coloring. These vortices generate intensive mixing.

CONCLUSIONS

With this experimental technique we present a method for the characterization of the performance of micromixers. We achieve higher resolution which is independent of the Péclet number of the investigated fluids and the methods allows the undisturbed observation of regions deep in a microchannel.

On one hand the resolution of the measurement itself is limited by diffusion of the tracer. On the other hand, in a mixing application the combination of advection, which increases the contact area and decreases the mixing path, and diffusion, which mixes at a molecular scale, creates efficient mixing. For the determination of mixing of an arbitrary species with known diffusion coefficient D, the mixing length of the species is added on the measured advection pattern.

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REFERENCES