MEASURING THE 3D MOTION OF PARTICLES IN MICROCHANNEL ACOUSTOPHORESIS USING ASTIGMATISM PARTICLE TRACKING VELOCIMETRY

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ABSTRACT

We introduce full three-dimensional tracking of particles in an acoustophoresis microchannel using Astigmatism Particle Tracking Velocimetry (APTV) [1]. For the first time the interaction between acoustic streaming and the primary acoustic radiation force in microchannel acoustophoresis are examined in three dimensions. We have quantified the velocity of particles driven by the primary acoustic radiation force and acoustic streaming, respectively, using 0.5-µm and 5-µm particles. Increased ultrasound frequency and lowered viscosity of the medium reduced the influence of acoustic streaming relative to the influence from the acoustic radiation force. The current study opens the route to optimized acoustophoretic system design and operation to enable manipulation of small biological components such as spores, bacteria and viruses.

KEYWORDS

Ultrasound, Acoustic streaming, Acoustic radiation force

INTRODUCTION

An ultrasonic standing wave in a particle suspension inside a microchannel drives, via radiation forces, an acoustophoretic motion of the particles in the horizontal *xy*-plane, (Fig. 1a). The acoustic field inevitably also induces 3D acoustic streaming of the suspending fluid itself, (Fig. 1b). For larger particles, e.g. cells or microbeads, the streaming motion is slow in comparison to the velocity induced by the acoustic radiation force. For small particles however, e.g. bacteria and virus particles, the Stokes drag from acoustic streaming is the dominating velocity component. We have previously investigated the interplay between acoustic radiation forces and acoustic streaming, but limited to the *xy*-plane using conventional top-view micro particle image velocimetry (µPIV) [2].

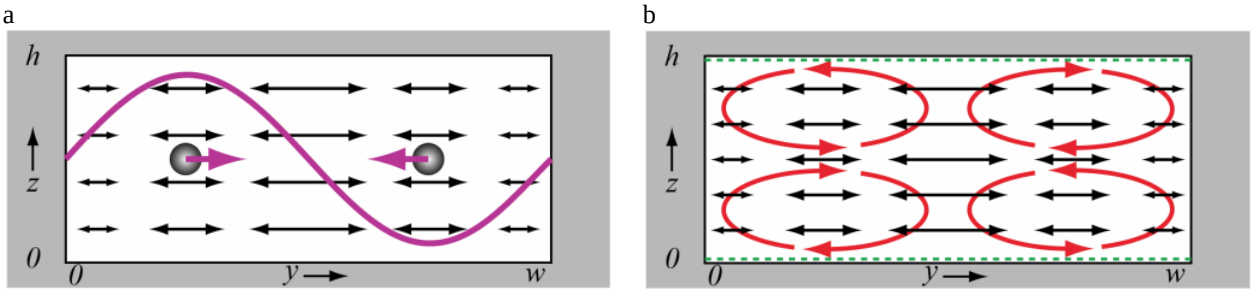

Figure 1. (a) A schematic of the acoustic radiation force (violet line) on a spherical particle in the transverse cross section of an acoustophoresis channel. The acoustic radiation force is induced by the harmonically oscillating first-order velocity field (black arrows). (b) A schematic of the theoretical prediction by Rayleigh (1884) for acoustic streaming (red arrows) also induced by the first-order acoustic velocity field. The streaming originates from dissipation of acoustic energy in the thin acoustic boundary layers (green dashed lines).

EXPERIMENT

Suspensions of polystyrene particles (diameters 0.5 and 5 µm) were exposed to an ultrasound resonance in a rectangular cross section acoustophoresis microchannel [3]. Microscope images of a 1-mm long section of the channel were analyzed. The acoustophoretic motion of the particles was tracked using APTV. The effect of frequency and suspending medium on the relative streaming component for small particles was characterized using conventional µPIV at mid height in the channel for particles ranging from 0.6 µm to 10 µm.

RESULTS AND DISCUSSION

Figure 2a shows the measured acoustic streaming rolls as projected on the vertical *yz*-plane of the channel for 0.5-µm beads. Clearly, the acoustic radiation force has minimal influence on the trajectories. Figure 2b shows the measured acoustophoretic motion of the 5-µm particles in the same acoustic field. The particles are subject to a vastly larger acoustic radiation component and reach the channel center shortly after the onset of sound. In the vertical *z*-direction there is no acoustic radiation force, and the particles will thus follow the acoustic streaming rolls and end up near the floor or ceiling of the channel. Figure 3 shows experimental evidence that an increase in frequency diminishes the influence of acoustic streaming as predicted by theory. Also, a medium of higher viscosity makes acoustic streaming more pronounced.

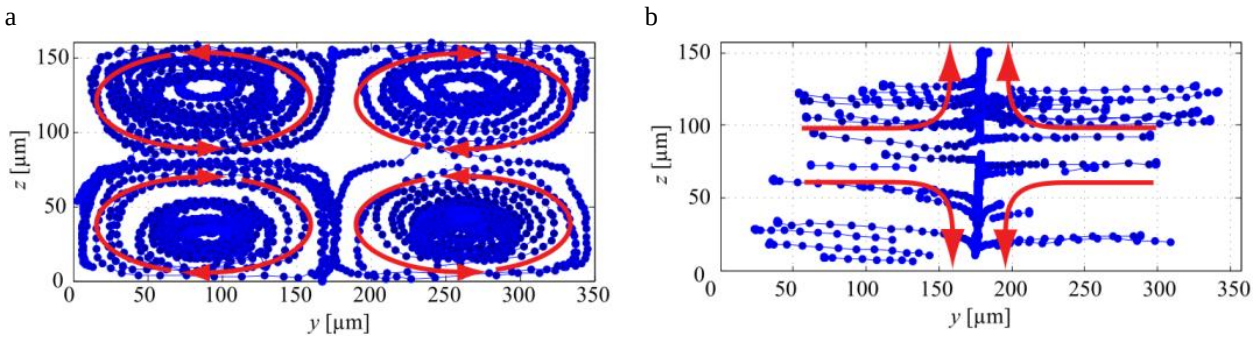

Figure 2. (a) Streaming motion of 0.5-µm polystyrene beads as measured by APTV. For sub-micron beads the acoustic radiation force is negligible compared to the Stokes drag force through the acoustic streaming. The measured streaming rolls display similar pattern as predicted from theory (Fig. 1b). (b) Motion of 5-µm polystyrene beads in the same acoustic field as in (a), as measured by APTV. First, the acoustic radiation force translates beads along y to the center of the channel. Thereafter, beads are pushed towards the channel floor and ceiling by the acoustic streaming since the acoustic radiation force has no component along z in this acoustic field.

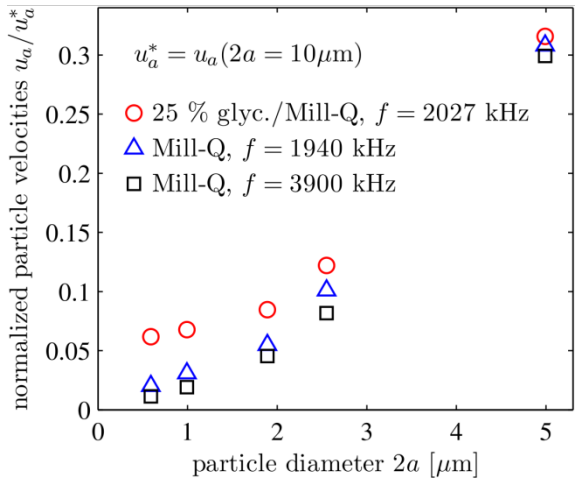

Figure 3. Velocity for 1, 2, 3, and 5-µm beads as measured by standard 2D µPIV at z = h/2. The bead velocities are normalized to the velocity u_a^* of 10-µm beads, where the acoustic streaming is negligible. When the frequency is doubled from 1940 kHz (blue triangles) to 3900 kHz (black squares) the radiation force increases and the influence of the streaming decreases. Increasing the viscosity of the suspending medium (glycerol 25%, red circles) leads to a decrease of the particle velocity induced by the acoustic radiation force and thus the influence of the streaming increases.

CONCLUSIONS

We have examined the interaction in three dimensions between acoustic streaming and acoustic radiation inside an acoustophoresis microchannel using three dimensional APTV. Better understanding of this interplay may enable new separation strategies for small (≤ 2µm) biological components. The study aims at lowering the limiting particle size in microchannel acoustophoresis below the characteristic sizes of bacteria and viral particles.

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