Numerical simulation of 3D acoustophoretic motion of microparticles in an acoustofluidic device

Junjun Lei, Peter Glynne-Jones and Martyn Hill

Faculty of Engineering and the Environment
University of Southampton
University Road, Southampton, SO17 1BJ, UK
Email: j.lei@soton.ac.uk

Introduction

Acoustic streaming is typically found in addition to acoustic radiation forces in acoustofluidic devices. Simulation of acoustic streaming is a crucial step for the understanding of its origins, which can provide efficient guidance on creating designs to limit or control this phenomenon. However, most existing methods can only simulate the streaming field in a local area, typically a cross-section of fluid channel. In this work, the three-dimensional (3D) Rayleigh streaming pattern in an acoustofluidic device is simulated and its effects on the movement of microparticles with various sizes are demonstrated. The viability of the simulation of 3D Rayleigh streaming presented here not only can provide better understanding and more comprehensive prediction of experiments in full acoustofluidic devices, but also can offer instructions on the simulation of unusual acoustic streaming patterns, e.g. transducer-plane streaming.[1]

Model and method

Fig. 1(a) shows the full model used to simulate the 3D acoustophoretic motion of microparticles, which is the one presented in[2]. A schematic of different layers and the dimensions of the device are shown in Fig. 1(b). The fluid channel has a dimension of 1 mm x 0.377 mm x 0.157 mm (x x y x z). The acoustic streaming field was simulated from the *limiting velocity method*, which only predicts the streaming field outside the viscous boundary layer and does not calculate the streaming velocities inside the viscous boundary layer. This is generally useful in real acoustofluidic devices working at MHz region where the thickness of viscous boundary layer is typically several orders smaller than the dimensions of the fluid chamber such that only the streaming field outside the viscous boundary layer is of interest.

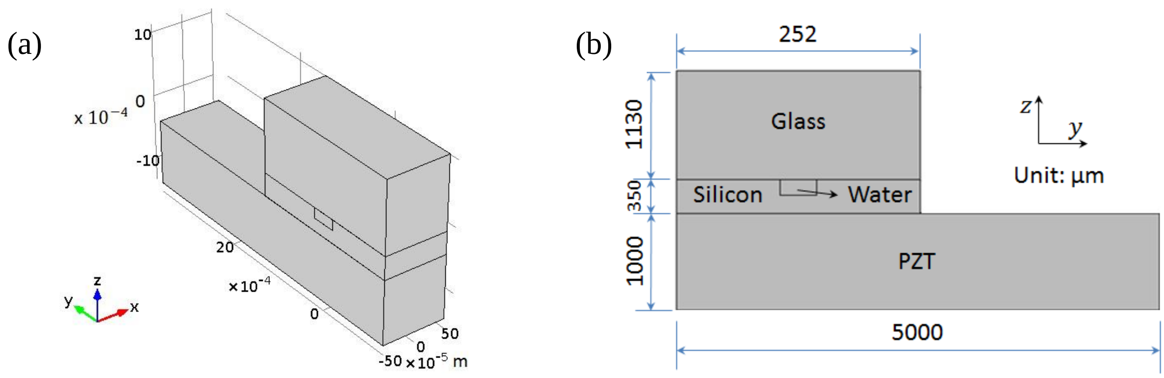

Fig. 1. (a) The 3D full model considered; (b) yz cross-section of (a)

The model was implemented in the finite element package COMSOL[3]. Three steps were used to simulate the acoustic streaming field and present the effects of acoustic streaming on the movements of particles. Firstly, a ‘Pressure Acoustic’ model was used to obtain the first-order acoustic pressure and velocity field, from which the limiting velocities can be derived. Then, a ‘creeping flow’ model was used to simulate the acoustic streaming field with the limiting velocities derived from the first model working as limiting velocity boundary conditions. Finally, a ‘particle trajectory for fluid flow’ model was used to simulate the particle trajectories under the combination of acoustic radiation forces (ARF) and acoustic streaming induced drag forces (ASF).

Results

The device was excited with a frequency of 1.936MHz. A lateral (y-axis) half-wavelength resonance was simulated (not shown) and a classical Rayleigh streaming pattern was obtained in the lateral direction (not shown). Based on the two models solved above, particle trajectories can be simulated with both ARF and ASF acting on the particles (polystyrene beads of diameter 0.5 μm and 5 μm), resulting in the motion shown in Fig. 3. It can be seen clearly that the movements of 0.5 μm particles are dominated by the ASF as the pattern the particle trajectories form is closely related to the acoustic streaming field. However, 5 μm particles are firstly driven to the pressure nodal plane by ARF and then slowly dragged to the up and bottom boundaries by ASF. Both of the trajectories of 5 μm and 0.5 μm are compared well with the experimental measurements from Muller et al..[2]

(a) (b)

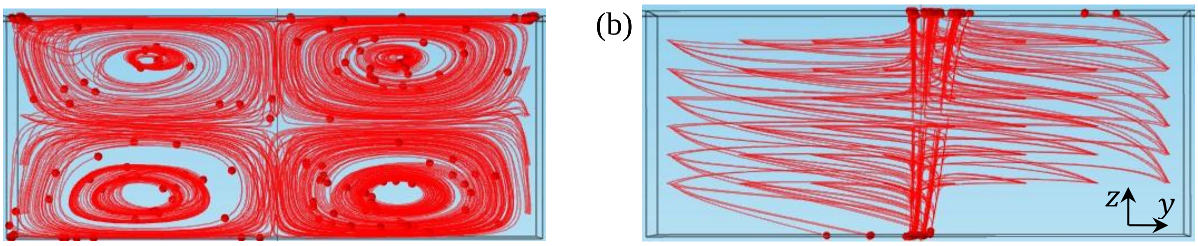

Fig. 3 Overall views along the channel axis (x-direction) of modelled trajectories of 0.5μm particles (a) and 5μm particles (b), where the particles are initially arranged in a 7×8×5 array

Conclusion

We have simulated the 3D Rayleigh streaming pattern in an acoustofluidic device using the limiting velocity method and demonstrated respectively the ARF-dominated and ASF-dominated particle motions. The results obtained from this model show much more explicitly the acoustic streaming field in full acoustofluidic devices compared to that obtained from simplified two-dimensional (2D) models and compare well with 3D measurements.

References

1. J. Lei, P. Glynne-Jones and M. Hill, *Lab Chip*, 2013, **13**, 2133-2143.
2. P. B. Muller, M. Rossi, A. G. Mar´ın, R. Barnkob, P. Augustsson, T. Laurall, C. J. K ̈ahler, M. J. H. Jensen and H. Bruus, *arXiv:1303.0201 [physics.flu-dyn]*, 2013.
3. Comsol Multiphysics 4.3, http://www.comsol.com/.