DROP ELECTROHYDRODYNAMICS

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Abstract

A novel methodology based on laser velocimetry for investigating electrohydrodynamic (EHD) flows in a leaky dielectric oblate drop is described. Using the Shake-The-Box (STB) method, the velocity field inside and outside the drop in a steady-state regime is analyzed for a drop with a 2.5 mm radius. It is the first time literature that such measurements are reported. The use of Castor oil as the continuous fluid and Silicone oil as the drop phase leads to the oblate shape under a constant electric field. Regarding the internal circulation of the drop, toroidal vortical structures along the zenith direciton are clearly identified, which are then symmetrical to the $y/a_o = 0$ plane.

Keywords: multiphase flow, electrohydrodynamic flows, Shake-The-Box method

Introduction

Electrohydrodynamic (EHD) flows are generated by electric stresses shearing at fluid interfaces. Among many EHD phenomena, the case of a leaky dielectric, neutrally buoyant drop stands out as a pivotal reference for electrohydrodynamic flows. Although this phenomenon has been investigated by decades [1], the available analytical solutions only cover a small range of drop deformations; thus far we rely on numerical simulations to investigate the velocity field of drop EHD flows. Experimental inquiries in this regard are scarce. Measurements of the velocity field have been reported for the first time by Karp *et al.* (2024) [2], who proposed a criterion below which the analytical solutions describe well the internal circulation, based on profiles of the radial and tangential velocity components inside the drop. However, additional experimental measurements are required to further address this issue. A three-dimensional evaluation of drop EHD flows would provide valuable insights into this topic. In this paper, we propose a novel methodology based on the Shake-the-Box (STB) technique to address this gap through 3D measurements of the velocity field in a Lagrangian reference frame.

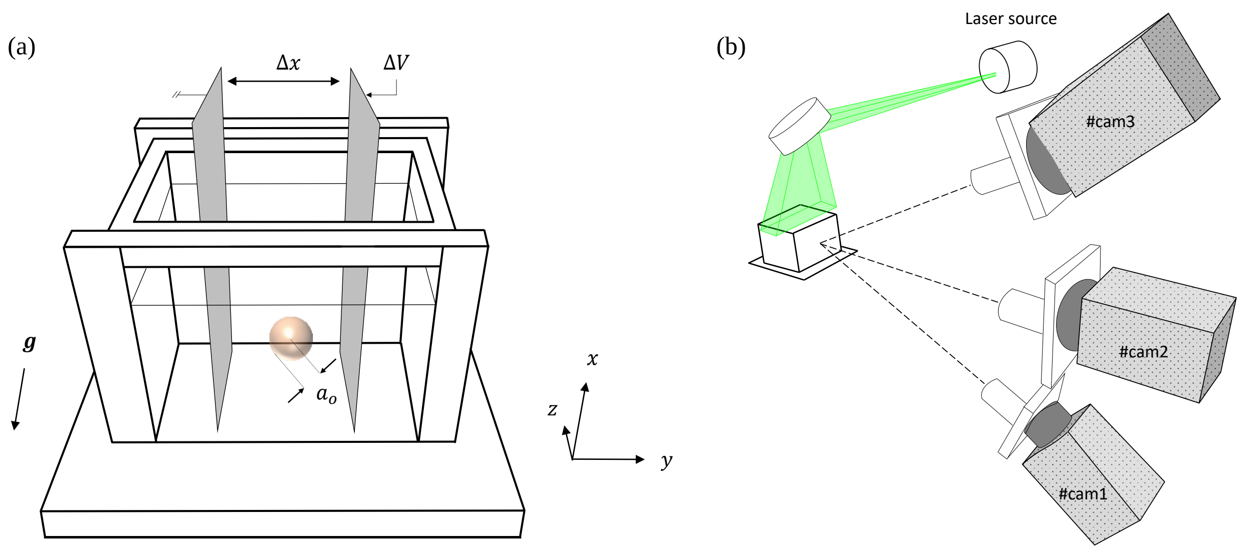


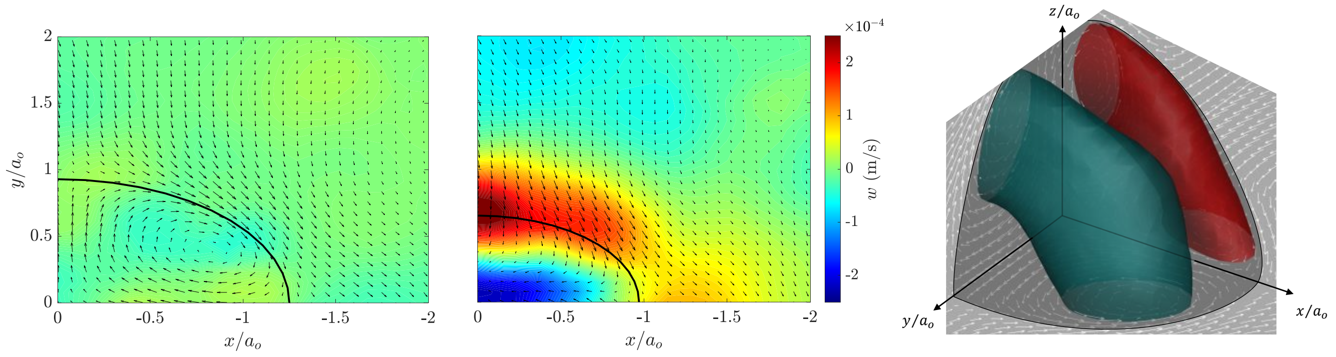
Figure 1: Cuvette showing the drop and electrode system (left) and in-line multiple camera arrangement (right).

Experimental methods

The experiments were performed in cuvette filled with Silicone oil (ρ = 970 kg/m^3, μ = 0.5 mPa.s), as shown in Fig. 1, in which two vertical copper electrodes are placed 20 mm apart. The electric field is generated using a high-voltage supply system to apply the desired voltage. A Castor oil drop (ρ = 961 kg/m^3, μ = 0.68 mPa.s) of fixed radius ($a_o = 2.5$ mm) is introduced using a micropipette. The strength of the electric field is set at $E_o = 1$ kV/cm. The EHD flows were quantified by adding RhodamineB tracer particles (20 μm) in the drop, whose volume is illuminated by a laser (Nd:YAG monocavity, 532 nm, 64 mJ, 20 Hz) sheet of 3 cm thick. An optical arrangement with three CCD cameras (HiSense Zyla, 2560 x 2160 pixels, 12 bits output) placed in line is employed to acquire images with different views. The Scheimpflug principle is used here to correct the effect of the inclination of the cameras, whose field of view of roughly 16 x 16 mm. The three-dimensional positions of the particles can be obtained from the raw images using the Shake-The-Box method (STB) using the software Davis 10 (LaVision, Germany), after a volumetric calibration and a self-calibration procedure. The characteristic value for reconstruction accuracy in the drop region is 0.25 voxel after calibration refinement.

Results and discussion

The velocity field is shown in Fig. 2 for different values of z/a_o. The velocity vectors are shown to visualize the circulation, while a scalar field of the velocity component perpendicular to the $x-y$ plane, w, is also shown. Clear vortical structures are observed at the plane of symmetry of the drop (a), where the flow is essentially planar. The internal vortex disappears at $z/a_o = 0.6$ (b), thus suggesting an evolution of the flow field along the depth of the drop. Interestingly, a w component of the velocity is identified outside the plane of symmetry suggesting the development of a three-dimensional structure of the velocity field in this region of the drop. From the iso-surfaces of the vorticity magnitude shown in Fig. 2 (c), toroidal vortical structures along the zenith direciton are clearly identified, which are then symmetrical to the $y/a_o = 0$ plane. Note that the contour of the drop is also shown for visualization purposes, thus clearly showing the three-dimensional nature of the EHD circulation inside the drop, as already inferred by the velocity fields shown in (a) and (b).



(a) (b) (c)

Figure 2: Slices in the $x-y$ plane of the velocity field in the for different values of $z/a_o = 0$ (a) and of $z/a_o = 0.6$ (b). Iso-surfaces of vorticity magnitude (c).

Conclusion

We describe a novel methodology to investigate the electrohydrodynamic (EHD) flows of an oblate leaky dielectric drop utilizing the Shake-The-Box (STB) method. It is the first time in literature that such measurements have been reported. Interestingly, the vortical structures inside the drop, where the recirculation is stronger compared to the external liquid, do not correspond to spherical zones of recirculation as one might expect; instead, a vortex tube deformed along the zenith direction is identified. The methodology hereby described provides accurate and reliable data to further comprehend drop EHD flows.

Acknowledgments

This project was financed by the Normandie region under the grant 22E05147.

References

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