Multiphysics Model for Breakup of Charged Liquid Droplets in Electric Fields

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Abstract

Predicting and controlling the formation of droplets from a liquid jet is a critical problem in a variety of applications ranging from fuel injection to paint sprays. It is known that liquid droplets subjected to an electric field acquire a net electrostatic charge via induction, and that the magnitude of this charge depends on the conductivity of the liquid and the size of the droplet [1]. When the direction of the electric field is aligned with that of the liquid nozzle, the charged liquid experiences electrostatic forces that accelerate and deform the droplets. With sufficient electric field strength, the forces can be strong enough to alter the size, shape, and velocity of the droplets forming from the jet. It is therefore possible to control the behavior of droplets by manipulating the electric field around it. However, despite progress in the modeling of charged droplets [2,3], applying these concepts to real-world applications requires much more robust and precise tools. This is due to the large number of coupled parameters dependent on operating conditions, geometric configuration of the spray instrumentation, and intrinsic knowledge on material and hydrodynamic properties. In this work, we seek to bridge this gap using simulations performed with COMSOL Multiphysics® software.

The formation and evolution of liquid droplets is intrinsically a multiphysics problem, coupling fluid mechanics, electrostatics and species transport via convection and diffusion. The jet and droplets are modeled as two-phase laminar flow with a liquid-gas interface, with a level-set method for interface tracking. The liquid acts as the convective medium for the electric charge, which is modeled as a charged species that is also transported by diffusion. The local charge concentration is used to calculate the electric potential and electric field strength within the computational domain. The coupling is completed by applying the calculated electrostatic forces to the fluid. Figure 1 shows the model configuration and boundaries.

The objective is to be able to accurately predict droplet dynamics for arbitrary liquids whose properties can be tuned for a specific application by varying formulation. Realizing this goal requires robust multiphysics models to generate the necessary results to map the relationship between controlled parameters and their resulting simulation results. To meet this requirement, substantial testing with different mesh and solver settings has been performed. We demonstrate the effectiveness of the methodology by presenting results for several charging scenarios in which droplets of various sizes and velocities are created. As shown in Figures 2 and 3, our results indicate that droplet size and velocity are determined by the electric potential and charge density in non-linear fashion, with smaller and faster droplets being formed at higher potentials.

We conclude by discussing the key physical and numerical issues encountered such as role of viscosity and charge migration inside the fluid. Among future research directions, applications in paint spray, electrostatic synthesis in nanojets and the limits of this methodology will be discussed.

Reference

1. A.G. Bailey, Electrostatic spraying of liquids, Wiley, New York (1998).

2. G. Tomar et al., Two-phase electrohydrodynamic simulations using a volume-of-fluid approach, Journal of Computational Physics, vol. 227, pp. 1267-1285 (2007).

3. N. Toljic et al., Charge to radius dependency for conductive particles charged by induction, Journal of Electrostatics, vol. 68, pp. 57-63 (2010).

Figures used in the abstract

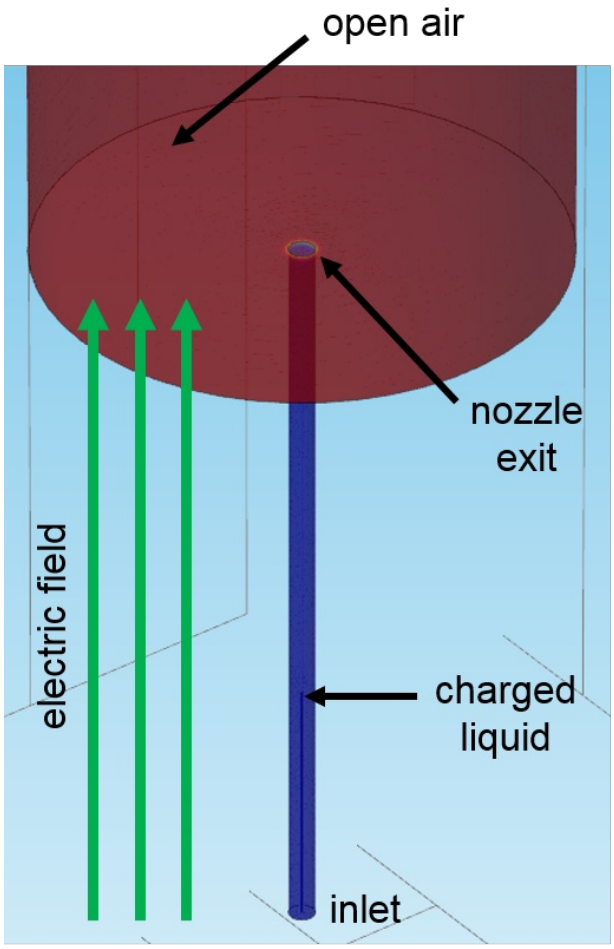

Figure 1: Figure 1: Computational setup for simulations with phase initialization shown (blue = liquid, red = air).

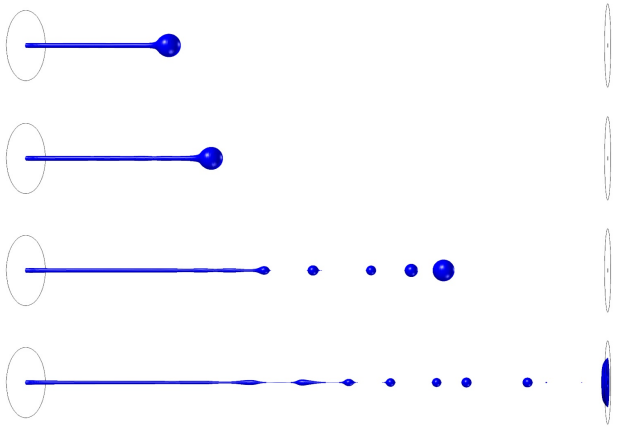

Figure 2: Figure 2: Liquid jet and droplets at t = 1.25 ms for reference force ranging from 3.9×105 N/m3 (top) to 1.2×10^7 N/m^3 (bottom).

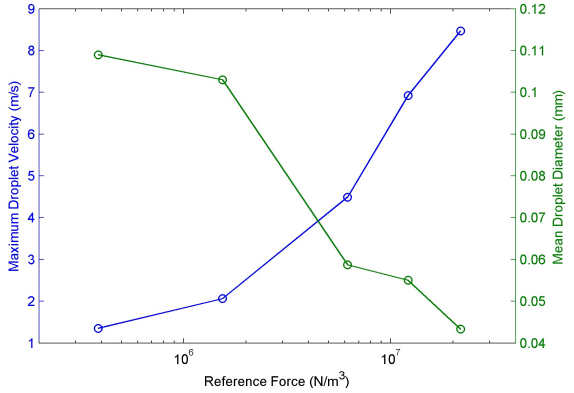

Figure 3: Figure 3: Maximum droplet velocity and mean droplet diameter with respect to reference force.

Figure 4