Jetting of Charged Bulk Water Drop Evaporating in Strong Electric Field

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I. INTRODUCTION

The stability of a charged liquid drop has been an interesting topic for more than a century due to its wide implications such as sprays, aerosols, ink-jet printing, and lightning in a cloud. In 1882, Rayleigh [1] developed a mathematical model to predict the instability of a charged liquid drop. Decades later, Taylor [2] studied the breakup of an uncharged water drop in an electric field. Recently, Shrimpton [3] combined both Rayleigh and Taylor to consider both the drop charge and the external electric field simultaneously. Almost all experimental studies so far have been conducted with micron-scale liquid drops, which makes it extremely difficult to capture the dynamics of a drop. This paper summarizes our efforts to visualize the instability of a charged millimeter-scale water drop in a strong electric field.

II. INSTRUMENTATION AND EXPERIMENTS

A series of experiments were conducted using the Solution Electrostatic Levitator (SEL) developed at Iowa State University. SEL levitates a charged (~400 pC) liquid drop of 2.5-3.5 mm in diameter within a strong (~10^5 V·m^{-1}) electric field. As the levitated drop evaporates, its diameter decreases down to ~0.5 mm and the surface charge density increases. As the coulomb force between surface charges approaches to the surface tension force, the drop becomes unstable and deforms into a prolate spheroid. Upon further evaporation, when the surface charge density reaches the jetting limit [1], some of surface charge is ejected by jetting and the drop regains its near-spherical shape (Figure 1).

III. RESULTS AND DISCUSSIONS

Figure 1 also shows the combination of the electric field around the drop and the radius at the moment of jetting. At a given radius, a drop becomes unstable if the electric field around the drop exceeds the instability limit. The SEL samples jetted at 38.1-78.8% of the jetting limit proposed by Rayleigh [1] when the influence of the external electric field is not considered (□), which is considerably lower than micron-sized drops (>95%) [4]. For the micron-sized drops, ignoring the influence of the external electric field yielded much smaller errors because its magnitude was as small as ~10^3 V·m^{-1} (~10^5 V·m^{-1} for SEL). When the effect of polarization and charge concentration induced by the external electric field is considered using Shrimpton's model [3], the SEL samples were found to jet at ~100% of Rayleigh's jetting limit (○). The result implies that the same physics applies to both micron- and millimeter-scale drops. This study opens up new possibilities to elucidate the unknown physics of micron-scale drops using millimeter-scale drops with proper scaling.

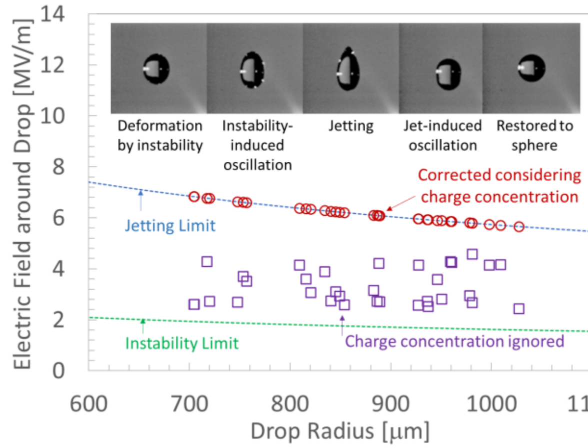

Figure 1: Electric field around the LESL water drops at the moment of jetting.

ACKNOWLEDGEMENTS

This research is based on work supported by NASA under Grant NNX16AB40G and by National Science Foundation under Grant No. 2132131.

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