FIELD INJECTION ELECTROSTATIC SPRAYING

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I. INTRODUCTION

Electrostatic spraying is the disruption of a liquid surface by electrical forces resulting in the formation of charged droplets. The physics of electrostatic spraying were first systematically examined by Lord Rayleigh in the late 1800's. He calculated the critical amount of charge that is necessary to destabilize a spherical droplet and observed that the resulting instability is a liquid jet that protrudes from the electrified droplet.[1] These jets then break up, forming small, stable, charged droplets. Since then, a number of investigators have examined the generation of charged droplets by electrostatic spraying.[2-13] Most of this work has been done using conducting fluids. Swatik and Hendricks[7] and more recently Stimpson and Evans[8] have demonstrated that individual ions of conducting liquids can be sprayed. It is interesting that Drozin[9] as well as Burayer and Vereshchagin[10] conclude that very low conducting fluids cannot be sprayed, while Hendricks et al.[11] and more recently Bailey and Borzabadi[13] were able to spray insulating fluids in large droplets at a low rate.

The formation of electrically driven jets has also been investigated.[14-18] Taylor[14] examined jets of water, glycerine and silicone oil and observed their breakup due to both sausage and kink instabilities. Melcher and Warren[15] also formed jets of glycerine, and by theoretically examining their stability, were able to successfully explain their behavior. Hoburg and Melcher[16] observed jets of water that were stable until corona discharge reduced the current flow in the jet. Kim and Turnbull[17] were able to form jets of Freon 113 by using a sharp needle to inject charge into the fluid. Using the same technique, Woosley et al.[18] have driven jets of liquid hydrogen.

The generation of charged droplets of liquid insulators has several proposed and conceived applications. In controlled thermonuclear fusion, proposed Tokamak fusion reactors will need to be refueled. The most feasible refueling technique is to inject pellets of deuterium and tritium at high velocities.[19,20] Electrostatic acceleration of fuel pellets may become competitive with other acceleration techniques if droplets of deuterium and tritium with charge-to-mass ratios near the Rayleigh limit can be produced. If very small, charged droplets of hydrogren could be formed, say with a radius on the order of 0.01μm, then they could be called ion clusters. The use of an ion cluster beam to refuel magnetic confinement fusion devices has also been proposed.[21] Cluster beams might also be used for plasma heating[17] and possibly as a source for neutral and negative hydrogren ion beams by colliding the clusters at high velocities with alkali-metal coated surfaces.[22,23] In laser fusion, intense laser light is focused on pellets of deuterium and tritium. The electrostatic transport and manipulation of fuel pellets would be possible if charged pellets could be produced.[24] It may be possible to produce suitable droplets for these applications by electrostatic spraying.

The formation of liquid jets using the needle electrode scheme employed by Kim and Turnbull may find application in ink jet printing technology. In electrostatically generated ink droplet jets, a convex meniscus of conducting ink is formed at the orifice of a glass capillary, and a flat plate electrode is placed a distance from the ink hemisphere. When a voltage is applied to the flat electrode , there is an electrostatic attraction between the ink and the electrode. When this force exceeds the force of surface tension at the ink meniscus, an ink droplet is formed.[25] A needle electrode in the capillary positioned so that it extends just through the orifice would enhance this electrostatic attraction lowering the required voltages and relaxing the restrictions on ink conductivity. If the fluid jets observed by Kim and Turnbull can be formed in a pulsed mode, smaller droplets would form and the effective operating frequency of this ink jet configuration would be increased. Continuous droplet ink jets are formed by squirting conducting fluids under pressure through an orifice. The resulting jet is broken up by introducing a surface wave at the appropriate frequency, usually with a piezoelectric transducer.[25] Positioning a needle electrode in the orifice to charge the droplets would again relax the conductivity restrictions, and if the jet were driven electrically instead of hydrostatically, smaller droplets would form since the size of the resulting droplets is not related to the orifice radius.[17] It may also be possible to employ the needle electrode charging in the ink on demand configuration. In this method, a small piezoelectric transducer is bound to the outer surface of a cylindrical glass nozzle. Upon receiving a voltage pulse, the transducer generates a pressure wave which forms the ink droplet provided that the wave can overcome the surface tension of the ink at the orifice. Lost ink is replaced with a flexible tube running to an ink reservoir by capillary action which limits the ink refill time and restricts the operating frequency.[25] The use of a needle electrode at constant DC voltage would allow smaller voltage pulses to form the ink droplets. Again, if electrically driven jets can be formed in a pulsed mode, small ink droplets would be formed, reducing the ink refill rate and increasing the effective operating frequency of this configuration.

With this work, the investigation of using a sharp electrode to inject charge in insulating fluids is continued. A theoretical explanation of the dependence of the liquid jet radius on injected current, electrode voltage and fluid flow rate is offered, as well as additional data on jets formed with silicon oil.