Electrostatic Spraying of Liquid Insulators

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Abstract—**A method for generating drops of liquid insulators using electrostatic spraying is reported. This method differs from normal electrostatic spraying in the method of charging the liquid. A sharp needle placed in the liquid near the end of a capillary is raised to a high potential, thus injecting charge into the liquid. As the voltage is raised, a jet is formed electrostatically with the size of the jet decreasing with increasing voltage. A theoretical prediction of the jet radius as a function of current is obtained by finding the amount of electrical energy which goes into mechanical energy. Experimental results of the spraying of silicone oils are given and compared with the theory.**

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 was 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 Burayev and Vereshchagin [10] conclude that fluids with very low conductivity 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 they 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.

Paper IUSD 79-22, approved by the Electrostatic Processes Committee of the IEEE Industry Applications Society for presentation at the 1978 Industry Applications Society Annual Meeting, Toronto, ON, Canada, October 1-5. Manuscript released for publication June 29, 1979. This work was supported by the National Science Foundation.

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With this work, the investigation of using a sharp electrode to inject charge into insulating fluids is continued. A theoretical explanation of the dependence of the liquid jet radius on injected current, electrode voltage, and fluid flowrate is offered. Additional data on jets formed with silicone oil are presented and compared with the theory.

In ordinary electrostatic spraying, natural conduction is responsible for the charge which causes the electrostatic spraying. An ohmic model for conduction gives a relaxation time for charges to accumulate of

$$\tau = \epsilon \sigma \qquad (1)$$

where σ is the conductivity and ϵ the dielectric constant of the material. If the desired droplet frequency for the electrostatic spraying is much less than the reciprocal of the relaxation time, the fluid behaves like a perfect conductor. If, on the other hand, a droplet frequency much larger than $1/\tau$ is desired, the voltage must be raised exponentially with the droplet frequency. Thus if a high frequency of drops is desired from a poor conductor, another method of charge injection is needed for electrostatic spraying. A method which is presented here is to use a sharp needle to inject charge by either field ionization or field emission.

DESCRIPTION OF FIELD INJECTION ELECTROSTATIC SPRAYING

Field injection is a charge injection technique that has been successfully employed to drive the electrostatic spraying of fluids with conductivities too low to permit ohmic spraying [17]. Fig. 1 is a photograph of this technique used to spray silicone oil with a conductivity of 10^{-12} S/m. Intense electrostatic fields at the interface between a metal electrode and the surrounding fluid result in either field emission or field ionization depending on the polarity of the electrode. The process of field emission requires electric field intensities on the order of 5×10^9 V/m, while field ionization typically requires field intensities of 5×10^{10} V/m [19].

A suitable geometry for field injection is shown in Fig. 2. A sharp electrode is mounted in a glass capillary which supplies the fluid to be sprayed. The electrode, positioned so that the tip extends just through the orifice, is connected to a high-voltage power supply. When the voltage is raised to several kilovolts the necessary field intensities for field injection are established at the electrode tip, provided that its radius of curvature is less than about 1×10^{-6} m, and spraying begins.

Once the charges are injected into the liquid they are accelerated away from the tip by the electric field. The force

0093-9994/80/0300-0308$00.75 © 1980 IEEE