Electrostatic atomization—Experiment, theory and industrial applications*

H. Okuda[†,a)]
Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543

Arnold J. Kelly
Charged Injection Corporation, Princeton Corporate Plaza, 9 Deer Park Drive, Monmouth Junction, New Jersey 08852

(Received 6 November 1995; accepted 13 December 1995)

Experimental and theoretical research has been initiated at the Princeton Plasma Physics Laboratory on the electrostatic atomization process in collaboration with Charged Injection Corporation. The goal of this collaboration is to set up a comprehensive research and development program on the electrostatic atomization at the Princeton Plasma Physics Laboratory so that both institutions can benefit from the collaboration. Experimental, theoretical and numerical simulation approaches are used for this purpose. An experiment consisting of a capillary sprayer combined with a quadrupole mass filter and a charge detector was installed at the Electrostatic Atomization Laboratory to study fundamental properties of the charged droplets such as the distribution of charges with respect to the droplet radius. In addition, a numerical simulation model is used to study interaction of beam electrons with atmospheric pressure water vapor, supporting an effort to develop an electrostatic water mist fire-fighting nozzle. © *1996 American Institute of Physics.* [S1070-664X(96)90305-1]

I. INTRODUCTION

The use of electric charges for the atomization of liquids and fine powder coating has long been an active field of scientific research as well as industrial applications. Fuel injection, agricultural spray and paint spray are just a few of the areas where recent technological advances have made some of these concepts into reality. Electrostatic sprays offer a number of advantages over more conventional sprays. Charged droplets are naturally self-dispersive thereby avoiding droplet agglomeration which can occur in the convectional un-charged droplet sprays. Furthermore, electrostatic sprays can be controlled electronically and the droplet motion can be manipulated by the combination of electric and aerodynamic forces which can give a great advantage over the uncharged droplets for agricultural spray and fire-fighting spray.

Fine paint powders can be charged by direct injection of electron beams. Charged powers are attracted to grounded surfaces electrostatically coating front, back and corners equally, thereby avoiding the need for cumbersome multiple spraying from all the directions. By directly injecting electrons into a liquid or a gas, virtually unlimited atomization can be achieved thereby advancing the realization of electrostatic technology in many applications hitherto considered impossible.

Despite the promising characteristics of electrostatic sprays, an understanding of the physics underlying electrostatic spray generation has developed slowly. Only in the last 40 years have concerted efforts been made to gain a fundamental understanding of such sprays for the purpose of technological innovation. Various limits of charging on a given drop have been determined and theoretical predictions of charge and size distributions based on energetic and statistical mechanical grounds have been proposed.[1-3]

Lord Rayleigh showed that there is a maximum amount of charges that can be placed on a droplet given by

$$Q_R = 8\pi(\gamma\varepsilon_0)^{1/2} r^{3/2}, \tag{1}$$

or the charge per unit mass,

$$Q_R/M = 6(\gamma\varepsilon_0)^{1/2}/\rho r^{3/2}, \tag{2}$$

where ε_0 is the permittivity of vacuum, γ is the liquid surface tension and ρ is the liquid mass density.

For a very small droplet, the Rayleigh limit given by (1) breaks down when the radial electric field exceeds the surface emission limit. In this limit, the electric field is so strong that electrons and ions are expelled from the droplet surface. Using Gauss' law, the limiting surface charges under this condition is given by

$$Q_E = 4\pi\varepsilon_0 E_s r^2, \tag{3}$$

or the charge density,

$$Q_E/M = 3\varepsilon_0 E_s/\rho r. \tag{4}$$

Therefore, surface emission occurs for a droplet radius smaller than

$$r = 4\gamma/\varepsilon_0 E_s^2, \tag{5}$$

where E_s is of the order of 10^9 V/m for electron emission and 10^{10} V/m for ion emission from a metal surface. For a liquid, the limiting electric field is considerably smaller, of the order of 10^8 V/m. Note the limiting fields given are valid only in vacuum. If, for example, the charged drops are placed in a gas such as air, then the gas breakdown takes place well before the limiting electric field is achieved thereby carrying the surface charges away by the surrounding gas.

When a large drop breaks into smaller droplets, it is clear that a certain amount of energy in the form of mechanical or

*Paper 1IA1, Bull. Am. Phys. Soc. **40**, 1643 (1995).
†Invited speaker.
a)Electronic mail: okuda@theory.pppl.gov

