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Induction charging nozzle for flat fan sprays

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Abstract

An induction charging nozzle has been developed for use with a fully hydraulic, flat fan, water spray. Charging is achieved by passing the spray between two relatively small diameter electrodes whose position can be changed to impart the maximum deposition current on a collection screen. A simple, analytic model was first derived to gain fundamental knowledge about the relationships between the variables that determine the deposition current (x and y electrode position, power supply voltage, and nozzle pressure), and to aid in the prediction of the optimum electrode location. The nozzle was then tested to verify the trends indicated by the model and test the hypotheses concerning the choice of electrode design. The model and experimental data trends matched well. The hypothesis for using small electrodes to help avoid issues associated with electrode wetting was verified. As also indicated by the model, experiments showed that decreasing the x-spacing between the electrodes and the spray resulted in an increase in deposition current; however, in the experimental case, droplet impact issues were revealed as the x-spacing became very small. The best y-location, relative to the nozzle orifice, for the electrodes was also clearly revealed.

Keywords: Induction charging; Electrosprays; Sprays; Electrohydrodynamics; Pressure spray nozzle

1. Introduction

Charging water spray droplets could be beneficial for a number of processes. In fact, much work has been published by researchers interested in charging aqueous pesticide solutions to enhance deposition on foliage for not only economical, but ecological reasons as well [1]. Other researchers are interested in charging water sprays to investigate their impact on air cleaning potential [2,3]. The authors of this work are interested in exploiting the attractive nature of charged drops for collection purposes in new direct contact heat exchanger concepts which requires the use of a fully hydraulic, flat fan nozzle [4]. For whatever the reason, it is felt that a droplet charging scheme should be developed to charge water, or water-based solution sprays (of conductivity 10^{-4} S/m) generated from the common flat fan style hydraulic nozzles.

Because the working fluid is conductive in nature, an induction charging scheme is used for sake of practicality. Other investigators have thoroughly explored this and other charging processes [5–8], and these efforts will hopefully capitalize and expand on the knowledge gained by those accomplished researchers. For example, Law and Bowen [8] have developed and tested an induction charging nozzle for hollow cone sprays. Marchant and Green [7] developed a charging system for hydraulic flat fan nozzles that attempts to avoid issues of reverse ionization due to wetted high-voltage electrodes. This system is similar to a direct charging type setup as a portion of the water loop is held at a high potential and a grounded electrode is placed in the vicinity of sheet breakup to induce a higher potential field while using lower voltages ($\sim +6$ kV). Though creative, the measures taken to minimize current leakage through the water loop may conflict with practical applications. Inculet and Castle [9] have also developed an induction charging nozzle design for an air assisted nozzle with efforts, again, focused to avoid the issue of electrode wetting. Though relevant in identifying the issues at hand, the air assisted nozzle is not desirable for some applications (e.g. a high-pressure air system is required) and their air curtain design is also not entirely practical for the same reasons.

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The challenge still remains to develop a fully hydraulic, flat fan spray induction charging system. It is felt that the simplest charging system should be designed for sake of reliability, predictability, and practicality. Thus, the system will be based on passing the grounded, flat spray between two parallel, cylindrical electrodes held at a high potential. It should be mentioned that Law [5] has published many excellent papers that outline much of the theory and phenomena of the induction charging process. This paper will not attempt to recap the detail of his work, but rather continue from his conclusions and methods.

Simply put, the induction charging process makes use of the conductive nature of the fluid which is normally a barrier for the other charging processes [6]. Assume a positively charged high-voltage electrode is held in the vicinity of a spray stream. Because the liquid is conductive, negative free charges in the fluid move toward the electrode in efforts to neutralize the net charge in the region. At this point, the stream of water from the nozzle begins to break up due to natural surface instability phenomena, and as the droplets form, they essentially trap the negative free charges forming a net negatively charged drop [6,8]. Law [5] points out that in the ideal situation the droplets should form in the highest field region as this would produce the highest charge on the droplets for a given potential. He outlines a simple method to predict where this region would be and goes further to actually try to predict not only the current carried by the spray, but the expected charge-to-mass ratio for an average drop as well. This method is adopted and explored as a guide for this work; however, space limitations do not allow inclusion of the charge-to-mass ratio model development. The theory is then tested with the construction and testing of an electrode system.

2. Theoretical analysis

A concept sketch for the proposed charging system is detailed in Fig. 1. The system utilizes two, relatively small diameter, cylindrical electrodes. Many concepts and models are based on a parallel plate type geometry which, admittedly, is a more easily predictable geometry to model [9,10]. Also, as pointed out by Law and Bowen [8], as the size of the electrodes increases, so does its capacitance. The increase in capacitance results in an increased charge on the electrodes for a given potential, which may ultimately translate to an increased spray cloud current. Given this, the immediate conclusion is to maximize the size (and charge) on the electrodes. However, increasing the size of the electrodes increases the risk of droplet deposition on them for two reasons. First, size increase effectively increases the target area for droplet deposition. Secondly, the larger charge acts to increase the Coulombic force which attracts the newly formed, oppositely charged drops back to deposit on the electrodes provided the drops have insufficient momentum to escape the field. In either case, without some way to continuously clean the electrodes (as with the air curtain proposed by Inculet and Castle [9]), reverse ionization is more probable at higher voltages. The logic behind the proposed small electrode design is that the chance of droplet impact will be reduced due to the smaller target area. Furthermore, the small electrodes cannot support the formation of large droplets which can, under the right conditions, form into Taylor cones that lead to reverse ionization. This phenomenon has been shown to reduce the effect of the induction charging process [5]. It is further hypothesized that strategic placement of smaller electrodes can counter their loss of capacitance.

Law [5] points out that for induction charging to be effective, the fluid must be sufficiently conductive to allow

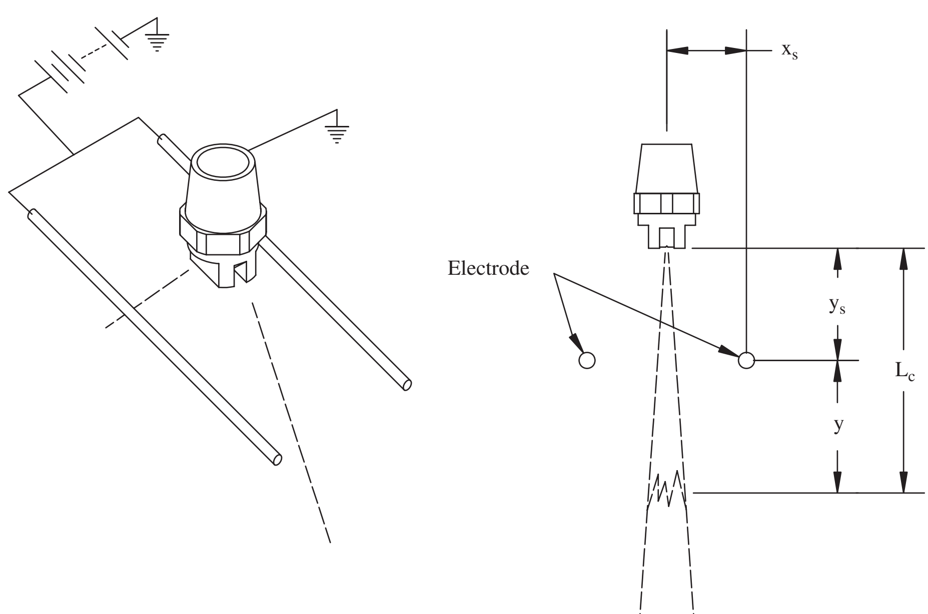

Fig. 1. Electrode placement relative to the flat fan spray.