Characterization of a variable charge induction nozzle for agricultural application

G. N. Laryea and S. Y. No

Dept. of Agricultural Machinery Engineering
Chungbuk National University, Cheongju, 361-763, Korea
Email : sooyoung@chungbuk.ac.kr

The application of a high voltage and electric field to enhance the atomization liquid has been an active research in recent years. This work deals with a research to determine experimentally and theoretically the charge to mass ratio of sprayed liquid at different electrode locations which forms part of an on-going development of a variable nozzle for agricultural application. The charge to mass ratio increased with an increase in applied voltage at low injection pressures, while the opposite occurred at higher injection pressures. The charge to mass ratio increased with an increase in the electrode location until it became saturated and then declined after 12 mm from the nozzle tip at injection pressures from 0.1 to 0.3 MPa. The charge to mass ratio increased with an increase in the gap between the spray edge and the inner ring at electrode location of 12 mm. The maximum charge to mass ratio was obtained at injection pressure of 0.1 MPa with applied voltage of 5 kV. The distance between the spray edge and the inner ring electrode which was occupied by electric field had an influence on the charge. The result indicates that, the liquid flow rate plays a major role on the charge carried on to the spray. The voltage and electrical field magnitudes at electrode locations of 6 and 12 mm from the nozzle tip and the spray width were also investigated by using the ALGOR software.

1. Introduction

Many electrostatic sprayers have been tested that provide favourable laboratory results, while field results have always been inconsistent due to many factors that affect the spray efficiency. The deposition of charged droplets under field conditions varies significantly from laboratory applications [1-3]. The transportation of charged droplets to the plant are influenced by many parameters such as droplet size, velocity of droplet, dynamics of the spray vehicle, weather conditions and physical properties of the plants. The electrical phenomena governing the deposition of the charged droplets, i.e. the electro-deposition process are the electrical field gradient between the atomizer and the plant [4]. The application of a high voltage and electric field to enhance the rate of charge on liquid has been an active research in recent years. Factors that influence the atomizer design include the electrode location, geometry, shape in the case of induction charging method and the electric field.

The principles behind the location of electrode for induction charging method have not been consistently applied and therefore not well understood. To ensure the maximum charging efficiency from the electrode arrangement, thus obtaining maximum charge to mass ratio of the droplets, the normal component of electric field present at the jet surface close to droplet formation zone, has to be maximized [5]. The ring electrode should have large exposure area to the liquid film and be able to produce the electrical field distribution required for maximum charge transfer efficiency at the liquid film. The ring should be placed within the nozzle body very close to the liquid film. The most suitable location for the electrode was 1mm from the orifice of the liquid supply tube [5]. For coaxial induction type, the electrode was positioned very close to the liquid jet with a 1.3 mm gap [6]. A ring electrode embedded in a nozzle adjacent to primary atomization region was 4.67 mm [7].

By modeling electrostatic-based pesticide sprays, the system was arranged such that the breakup of the jet occurred inside the cylindrical electrode [8]. The magnitude of spray droplet charge imparted by electrostatic induction should theoretically depend upon the relative time rate of charge transfer onto the droplet formation zone as compared with the time t, characterizing the droplet formation event [9]. The close coaxial spacing (1-2 mm) of the induction electrode, around the droplet formation jet within the near-sonic nozzle, provides intense charged fields i.e. 1-2 MV/m at relatively low electrode voltage of 1 kV [10]. Electrostatic pressure-swirl nozzle with a brass ring electrode located at 10 mm from the nozzle tip had been developed and tested [11.

The purpose of this study is to develop a variable electrostatic nozzle for agricultural application and investigate the effect of optimum electrode location on spray characteristics.

2. Experimental Methods and Materials

A tap water without a surfactant was pumped from a 2-plunger reciprocating pump at varying operating pressures between 0.1 and 0.5 MPa. The spray characteristics of this conventional pressure-swirl nozzle type with orifice diameter of 0.59 mm had been studied [12] with a different experimental condition. In this experiment, a liquid mass flow rate between 1.9 to 4.23 x 10^{-3} kg/s, was selected for the study. The cross-sectional view of the designed holder for a variable charge induction nozzle is presented in Fig. 1.

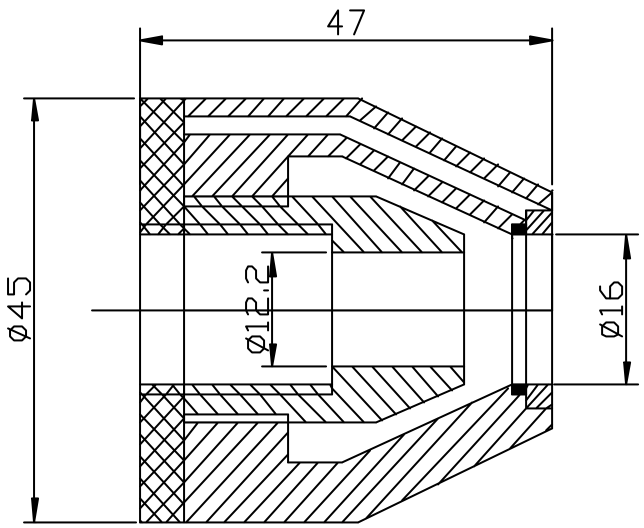

Fig. 1 Cross-sectional view of the designed holder for a variable charge induction nozzle

An induction charging method with embedded brass ring electrode, of inner diameter of 16 mm in a PTFE material, was designed in the laboratory and manufactured at the System Engineering Department Brunel University, London. The electrode was connected to a high voltage DC power supply with a positive polarity; and voltage was varied from 1.0 to 5.0 kV. The electrode location was also varied at 3, 6, 9, 12 and 15 mm downstream from the nozzle tip.

The spray current at each electrode location of the nozzle was measured by connecting the Keithley electrometer to a Faraday cup placed in a Faraday chamber. As the charge current was not stable and difficult to read, the electrometer was connected to a PC with a Keithley IEEE Interface Programme for online analysis. In each application, 30 measuring counts at 5 s interval was selected and an average value was determined for off-line analysis. The most frequent equation use to determine the charge to mass ratio has been shown in Eq.1 and also described elsewhere [12].

$$\frac{q}{m} = \frac{I_c}{Q_m} \qquad (1)$$

$$Q_m = C_D A\sqrt{2\Delta P r_l} \qquad (2)$$

where q - charge on droplet [C], m – mass of droplet [kg]. Q_m - mass flow rate [kg/s]; I_c - spray cloud current [A]; C_D - discharge coefficient [-], A - nozzle orifice area [m^2]; ΔP - total pressure drop [Pa] and ρ_l - mass density of the liquid [kg/m^3].
These spray width measurements were needed to help investigate the effect of distance between the spray edge and inner ring electrode on charge to mass ratio. They may also serve as an input data for the ALGOR programming needed to study the voltage and electrical field magnitude distributions. The attached nozzle holder made the measuring positions impossible so it was removed before spraying and photographs were taken (i.e. without voltage). Thirty images were captured by using a 3-CCCD video camera with back illumination method for off-line analysis. Each image was processed with PHOTOSHOP for the thresh holding processes and the PAINTSHOP software was used to measure the spray width at the selected locations. The spray widths were needed to investigate the voltage, and electrical field magnitude distributions between the spray edge and the electrode inner ring.
The ALGOR software (i.e. electrostatic analysis type) was used to investigate the voltage and electrical field magnitude distributions at the electrode location where the maximum charge to mass ratio may occur with the corresponding voltage. The mesh was created and analyzed with a two-dimensional (2-D) model of the Superdraw III. Some of the input data such as spray current, voltage permittivity of free space and electrode ring diameter were used for the programming.

3. Results and Discussion

3.1. Charge to mass ratio verses applied voltage and electrode location from nozzle tip

Charge to mass ratio serves as the basic parameter that has to be determined in any electrostatic design due to charge limitations. The relationship between the charge to mass ratio and the applied voltage, with the variation of electrode locations from the nozzle tip is presented in Fig. 2. It can vividly be seen that, the charge to mass ratio increases with an increase in the applied voltage at low injection pressures such as 0.1 and 0.3 MPa. At injection pressure of 0.4 MPa, two peak values where obtained at electrode locations of 6 and 12 mm from the nozzle tip. In the case of an injection pressure of 0.5 MPa, the optimum charge to mass ratio was obtained at the 6 mm electrode location. An opposite charging behaviour of the applied voltage was observed at electrode location of 12 mm from the nozzle tip (i.e. an increase in voltage caused a decrease in the charge to mass ratio). This can be attributed to the charge characterization time, discharge velocity of the liquid as well the drop formation zone just after liquid sheet breakup.
The geometrical shape of pressure-swirl nozzles are simple in construction but the internal fluid flows are very complex to understand and this had proved the irregularities in the behaviour of the charge to mass ratio against the electrode location. In Fig. 2, it clearly indicates that it is advisable for the electrode ring not be located at 3, 9 and 15 mm from the nozzle tip when operating at injection pressures from 0.1 to 0.5 MPa.
This may prove that, for induction charge nozzle designs, the electrode location from the nozzle tip plays a vital role to obtain a maximum charge to mass ratio.

3.2. Charge to mass ratio verses distance from spray edge to inner ring

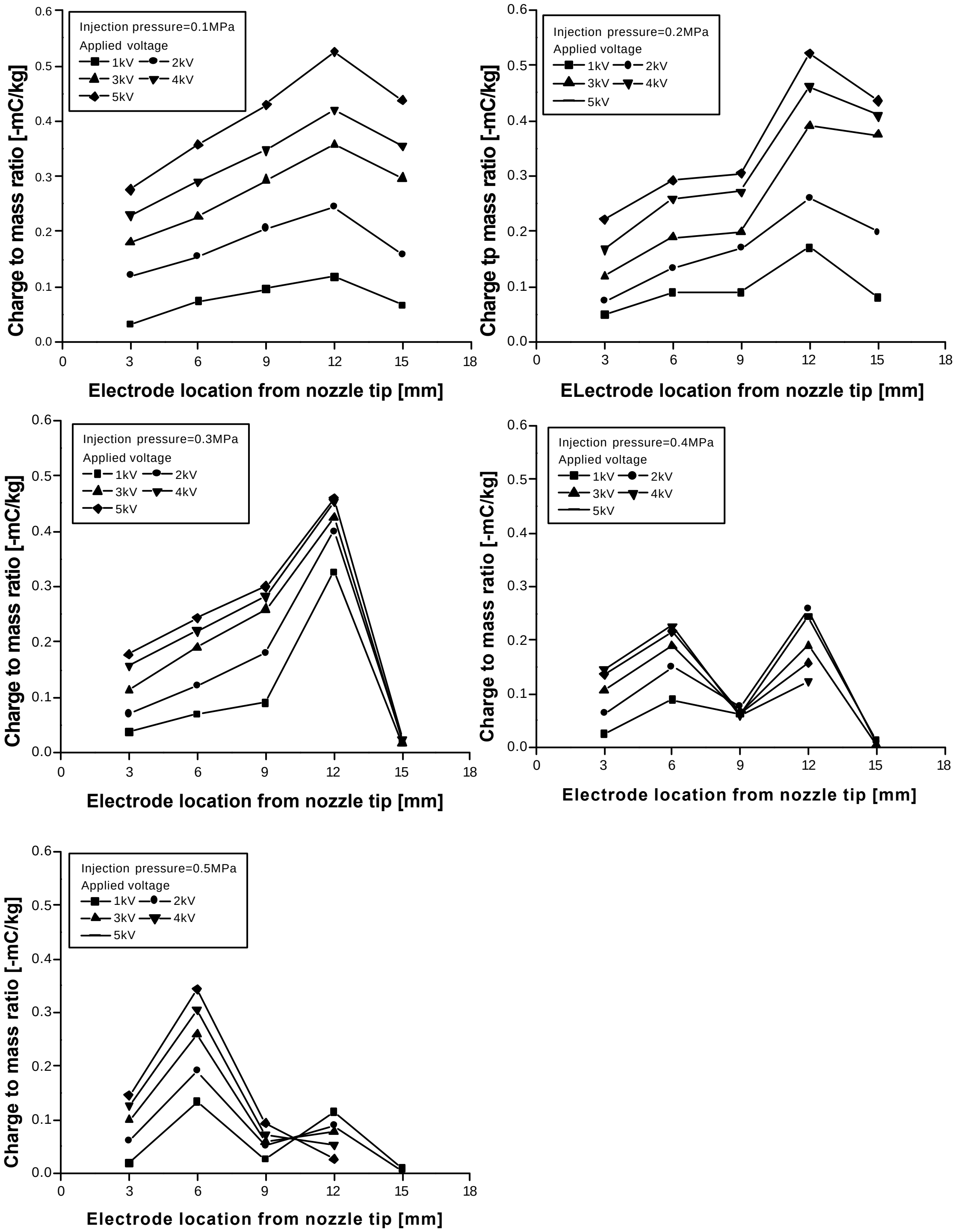

Fig. 2 Effect of applied voltage and electrode location from nozzle tip on charge to mass ratio with applied voltage.

Effect of distance from spray edges to inner ring on charge to mass ratio is shown in Fig. 3a. It shows that, initially, the charge to mass ratio decreased with an increase in the distance, between the spray edge and inner ring, and then began to increase again. When the distance between the spray edge and the inner ring was about 7 mm (i.e. at injection pressure of 0.1MPa), the charge to mass ratio increased consistently with an increase in applied voltage. This was in agreement with the one described in the literature [5], and in addition it may depend on the injection pressure. An increase in injection pressure of pressure-swirl nozzle causes a decrease in liquid sheet breakup length.

In Fig. 3b, the charge to mass ratio increased with an increase in the distance from spray edge and the inner ring to an optimum value and then decreased especially at voltages below 4 kV. With an applied voltage of 5 kV, an increase in the distance from the spray edge to the inner ring, caused an increase in the charge to mass ratio. This can be attributed to the high electric field intensity created between the spray edge and the inner ring electrode. There was no electrical breakdown under this experimental condition.

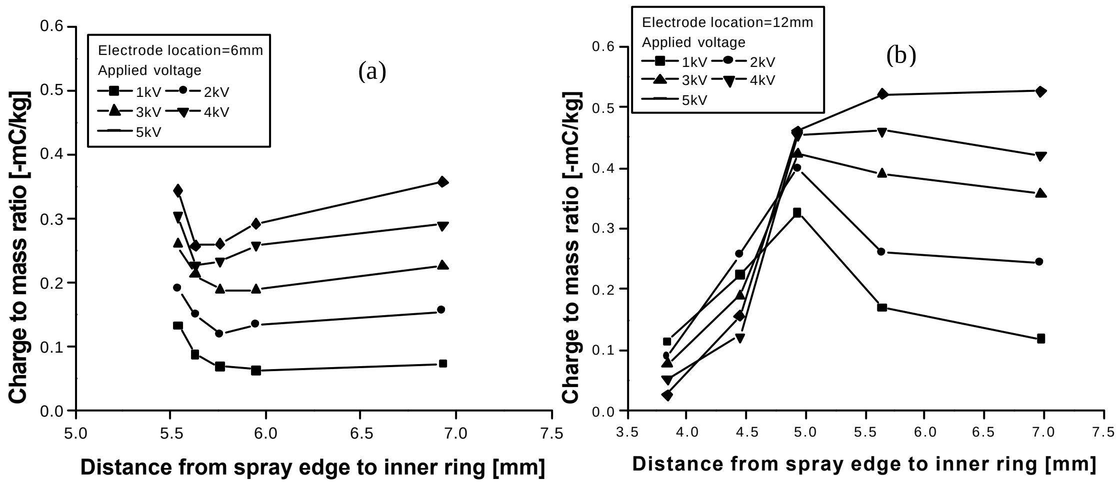

Fig. 3 Effect of distance from spray edges to inner ring on charge to mass ratio

3.3. Charge to mass ratio verses injection pressure

In Fig. 4a, it was observed that, at injection pressure of 0.1MPa, an increase in voltage, caused a consistent increase in charge to mass ratio. On the other hand, the charge to mass ratio decreased with an increase in injection pressure from 0.1 to 0.3 MPa with applied voltage not exceeding 3 kV and then increased again. For injection pressures of 0.4 and 0.5 MPa, the increase occurred at an applied voltage above 4 kV.

At electrode location of 12 mm from the nozzle tip, the charge to mass ratio increased with an increase in injection pressure from 0.1 to 0.3 MPa, and then, decreased at voltages not

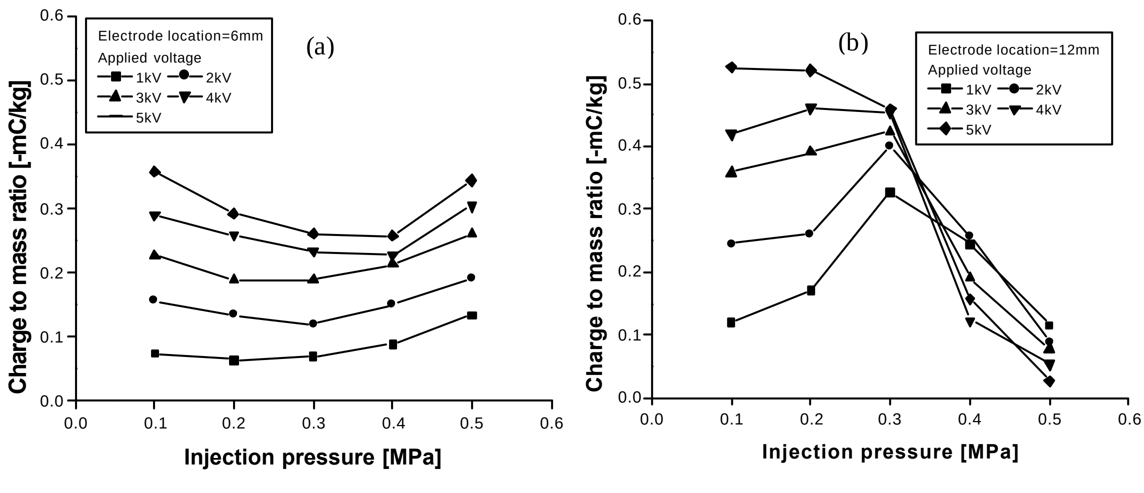

Fig. 4 Effect of injection pressure on charge to mass ratio with applied voltage

exceeding 4 kV. The maximum charge to mass ratio was obtained at injection pressure of 0.1 MPa, with an applied voltage of 5 kV, while an increase in injection pressure caused a decrease in the charge to mass ratio. Thus, effect of voltage increase was negligible at higher injection pressures. Although corona discharge or electrical breakdown was not experienced, it was observed that the applied voltage also played an important role in wetting the nozzle body. At 5 kV with low injection pressure, the rate of wetting was faster when compared to low voltages from 1 to 4 kV.

3.4. Voltage and Electrical Field Magnitudes Distributions

Figures 5 and 6 shows a typical examples of voltage and the electrical field magnitude distributions that occurred between the spray edge and the inner electrode at electrode location of 6 and 12 mm by using the electrostatic analysis of the ALGOR software. There was a slight difference in the electrical field magnitudes [V/mm] at electrode locations of 6 and 12 mm. This was due to the distance between the spray edge and the inner ring electrode, although the applied voltages were selected at their maximum charge to mass ratios. It was also observed that, the voltage and electrical field magnitude distributions were not uniform at some distance between the spray edge and the inner ring. It was assumed that, each droplet may be charged differently.

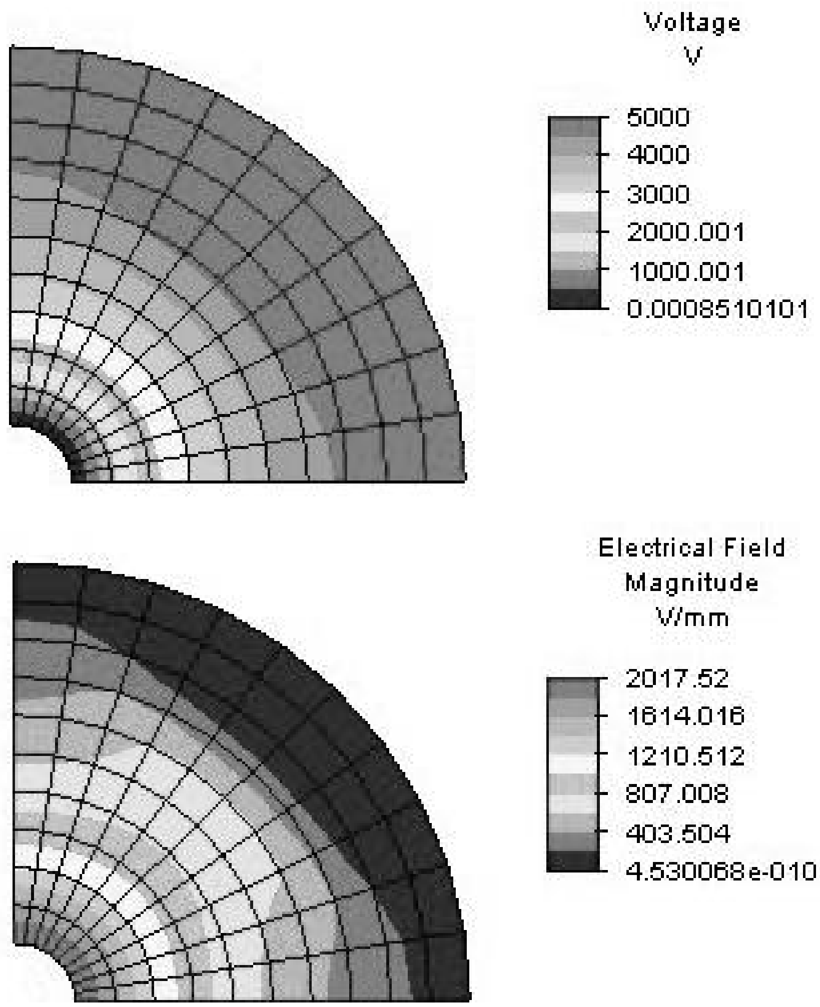

Fig. 5 Effect of voltage and electrical field magnitude distributions at electrode location of 6 mm from nozzle tip.

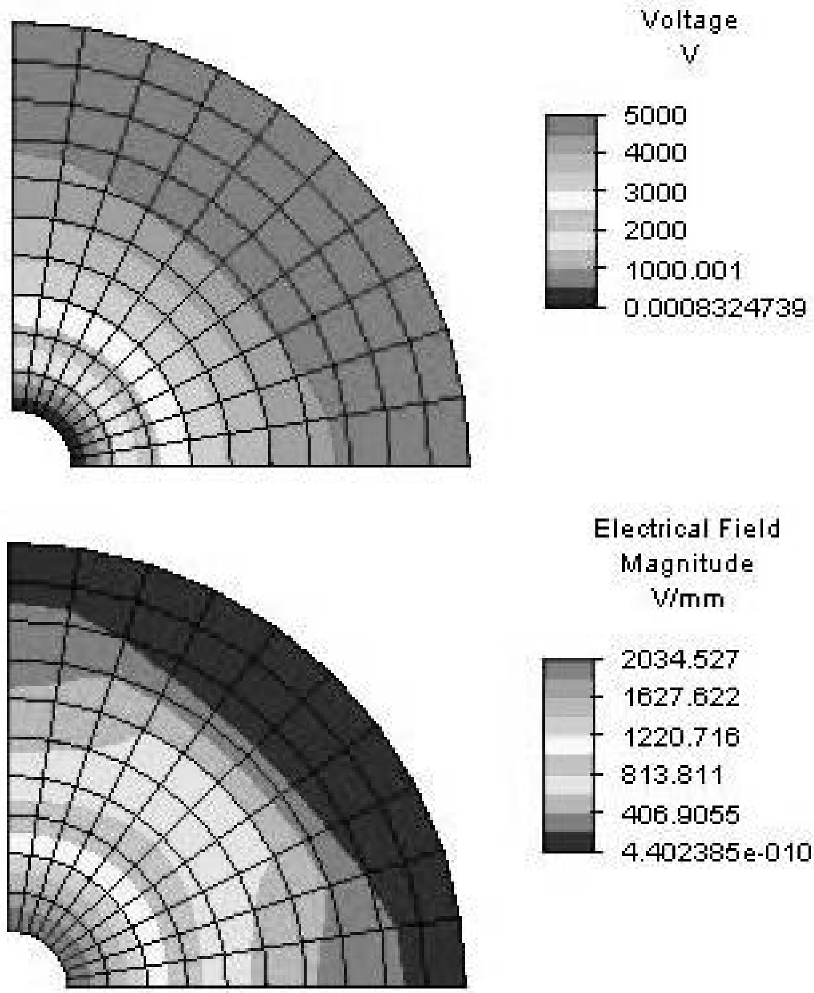

Fig. 6 Effect of voltage and electrical field magnitude distributions at electrode location of 12 mm from nozzle tip.

4. Conclusions

A variable induction charge nozzle for agricultural application has been designed and its charging performance has also been investigated. The following conclusions were drawn from this investigation:

1. Charge to mass ratio increased with an increase in applied voltage especially at low injection pressures, while the opposite occurred at higher injection pressures.

2. The charge to mass ratio increased with an increase in the electrode location from nozzle tip until it became saturated, and then began to decrease after 12 mm. At injection pressure above 0.4 MPa, two peak values for charge to mass ratio were obtained at electrode locations of 6 and 12 mm from the nozzle tip. At injection pressure of 0.5 MPa, the optimum charge to mass ratio was obtained at electrode location of 6 mm from the nozzle tip, while an opposite charging behaviour of the applied voltage was observed at electrode location of 12 mm from the nozzle tip. For induction charge nozzle designs, the electrode location from the nozzle plays a vital role in obtaining a maximum charge to mass ratio.

3. The charge to mass ratio decreased with an increase in the distance between the spray edge and inner ring and then began to increase again. The charge to mass ratio increased consistently with an increase in applied voltage at about 7 mm distance from the spray edge to the inner ring. In Fig. 3b, the charge to mass ratio increased with an increase in the distance from spray edge

and the inner ring to an optimum value and then decreased especially at voltages below 4 kV. This showed that the gap occupied by the electric field had an influence on the charged spray.

4. At electrode location of 6 mm from the nozzle tip, the charge to mass ratio decreased with an decrease in injection pressure from 0.1 to 0.3 MPa with applied voltage not exceeding 3 kV and then decreased. At injection pressures of 0.4 and 0.5 MPa, the increase occurred at voltages above 4 kV. The maximum charge to mass ratio was obtained at injection pressure of 0.1 MPa with an applied voltage of 5 kV. An increase in injection pressure caused a decrease in the charge to mass ratio. The charge to mass ratio increased with an increase in injection pressure from 0.1 to 0.3 MPa and then decreased with applied voltage not exceeding 4 kV, at electrode location of 12 mm from the nozzle tip. The maximum charge to mass ratio was obtained at injection pressure of 0.1 MPa with an applied voltage of 5 kV.

5. The electrical field magnitude depends on the applied voltage and the distance between the spray edge and inner ring electrode. It was observed that the voltage and electrical field magnitude were not uniformly distributed at some locations inside the ring.

5. Acknowledgement

The authors would like to thank the System Engineering Department, Brunel University, London, for the manufacture of the nozzle.

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