

## Effect of Electrostatic Induction Parameters on Droplets Charging for Agricultural Application

B. Mostafaei Maynagh<sup>1</sup>, B.Ghobadian<sup>1\*</sup>, M. R. Jahannama<sup>2</sup>, and T. Tavakoli Hashjin<sup>1</sup>

### ABSTRACT

In this study, an electrostatic sprayer which had been previously designed and constructed was evaluated in order to quantify the charging of droplets. Liquid atomization was achieved by using an ultrasonic nozzle. The nozzle maximum flow rate was 25 milliliters per minute and vibration frequency was about 30 kHz. The induction method was used for charging the output droplets. All experiments were carried out within a closed environment with a fixed ambient humidity and temperature to reduce the effect of environmental factors. The independent parameters in this study included: voltage at four levels of 1.5, 3, 5 and 7 kV; air flow speed at six levels of 14, 14.9, 17, 20.2, 21.6 and 23 m s<sup>-1</sup>; charging electrode radius in two levels of 10 and 15 millimeters, horizontal distance between the electrode and nozzle tip at four levels of 1.5, 6, 10 and 15 millimeters; and liquid flow rate at three levels of 5, 12 and 25 milliliters per minutes. For evaluation of the system, the charging quantities of droplets were measured in different states. The maximum charging occurred at 5 ml min<sup>-1</sup> flow rate, voltage of 7 kV, air flow speed of 23 m s<sup>-1</sup> and the resulting current was 0.24 μA. On dividing the electrical current by the liquid flow rate and changing the scale, the mean charge to mass ratio was 1.032 μC g<sup>-1</sup>. Increasing voltage increased the charging quantity slightly but higher voltages and lower air speeds decreased it. The effect of the faster air speed on droplet charging phenomena is positive and the smaller electrode radius causes less charge induction on the droplets. The quantity of droplets charging first increased with increased distance between ring electrode and nozzle tip, and then it was either reduced and/or fixed.

**Keywords:** Charged liquid droplets, Charged spray, Electrostatic spraying, Induction electrode.

### INTRODUCTION

The application of pesticide is still one of the most frequently used methods to protect crops and trees against diseases and insects in agriculture. Overdosage of pesticide is common in most countries, and its application leads to many problems such as chemical waste and environmental pollution from spray drift. One of the current trends toward prevention of chemical waste and environmental pollution is the application of an electrostatic technique in the agricultural spray (Laryea and No, 2004 and 2005; Matthews, 1992).

Electrical charging of pesticide droplets is a specialist technical domain, the advantages of which are increased spraying efficiency, pesticide deposition on plant targets and reduced drift. The review revealed the benefits of electrostatic charging technology as a means of increasing the deposition characteristics of the spray, and also for bringing many important environmental and cost-saving benefits (Bailey, 1986; Hilsop, 1987; Elmoursi, 1992).

Electrostatic crop sprayers provide improvements in the overall exploitation of toxic chemicals. In contrast, conventional crop sprayers bring about spray drifting into the surrounding atmosphere, deposition on

<sup>1</sup> Mechanics of Agricultural Machinery Department, Tarbiat Modares University, Tehran, Islamic Republic of Iran. Tel: 021-44196522

<sup>2</sup> Engineering Research Institute of Jihad-e-Agriculture Ministry, Tehran, Islamic Republic of Iran.

\* Corresponding author, e-mail: ghobadib@modares.ac.ir

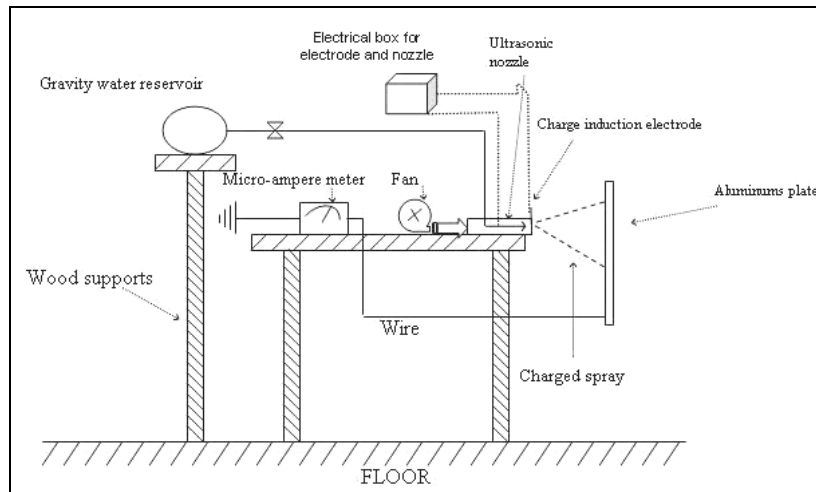


Figure 1. Experimental evaluation set up.

soil underneath the crops, and poor deposition coverage on foliage (Coffee, 1981; Law, 1984; Marchant, 1985).

This approach has drawn the attention of many researchers towards electrostatic spraying during the past twenty five years (Jahanama *et al.*, 1999; Law, 2001). Most agricultural pesticides are distributed as conductive aqueous solutions or in water-based carriers, characterized by electrical resistances in the range of  $1 \times 10^{-1}$  to  $1 \times 10^4$  m $\Omega$  (Law, 1987). There are different charging methods used for electrostatic spraying, including conduction

charging, induction charging and corona charging. Among these the induction charging is the most widely used because of the following advantages compared with conduction charging: (1) the high voltage does not directly contact the liquid; (2) the electric field strength is below the breakdown strength of the air, so its working voltage can be lower and electrode insulation becomes easier; (3) in principle, there is no current drawn from the power supply, therefore the current capacity can be very small (Zhao *et al.*, 2005). Out of the various liquid charging

Table 1. Various states of fan speeds.

N#1	N#2	N#3	N#4	N#5	N#6
9300 (rpm)	10300 (rpm)	11350 (rpm)	12100 (rpm)	13200 (rpm)	14050 (rpm)
14 (m s <sup>-1</sup> )	14.9 (m s <sup>-1</sup> )	17 (m s <sup>-1</sup> )	20.2 (m s <sup>-1</sup> )	21.6 (m s <sup>-1</sup> )	23 (m s <sup>-1</sup> )

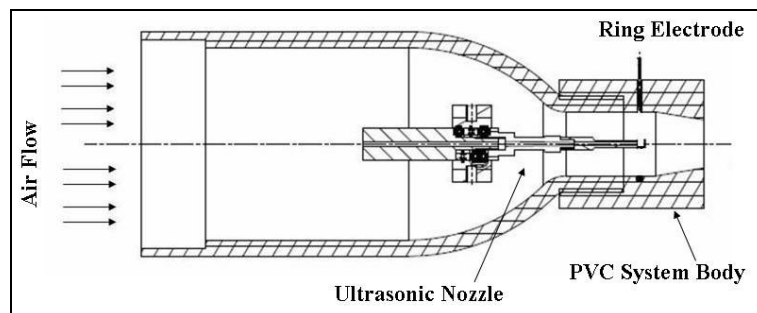
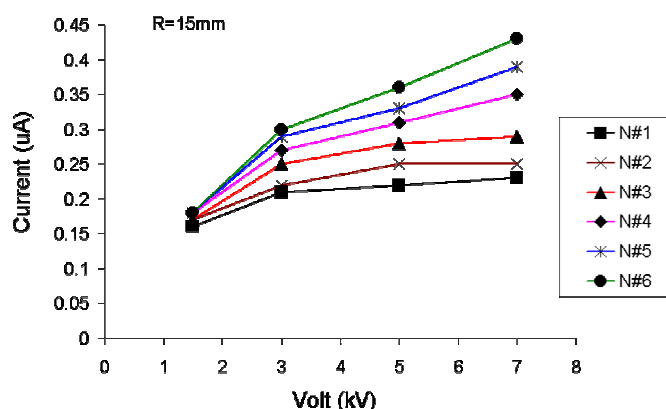


Figure 2. The electrostatic sprayer schematic.



**Figure 3.** Relationship between voltage and current for a 15 mm radius the electrode.

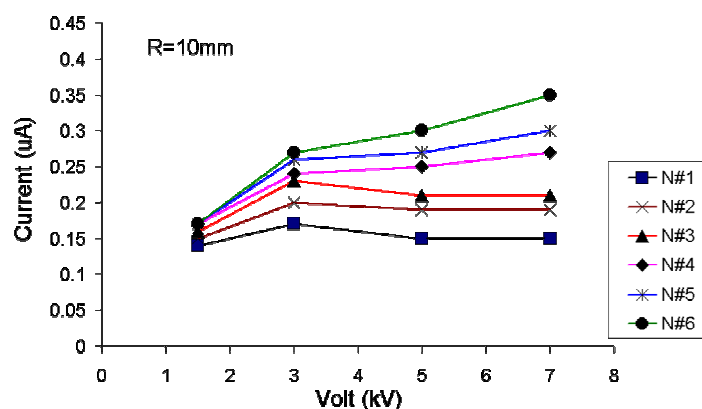
methods, the induction charging approach has appeared to be convenient and practical for the electrification of aqueous pesticides.

This research work was sponsored by Tarbiat Modares University in the form of an MSc. dissertation in the mechanical engineering of farm machinery. In this work, a new capacitive type of electrostatic induction spraying ultrasonic nozzle with a pulsed voltage was proposed and studied experimentally. The purpose of this article is to evaluate and quantify the charging of the droplets created by an electrostatic sprayer which had been previously designed and developed (Mostafaei, 2006). Several parameters such as solution characteristics, physical properties of the

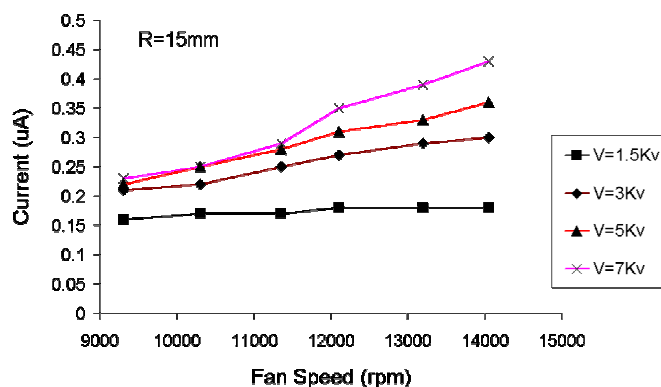
nozzle, the characteristic of electrical potential square influence on droplet charging. The independent selected parameters in this study included: voltage, air flow speed, radius of charging electrode, liquid flow rate and horizontal distance between the electrode and nozzle tip.

## MATERIALS AND METHODS

A charge collector, consisting of a  $70 \times 70$  cm<sup>2</sup> aluminum plate, captured the spray's charge and was suspended 0.3 m in front of the nozzle. A PVC frame guided the fan blowing air toward the system. The nozzle



**Figure 4.** Relationship between voltage and current for a 10 mm radius electrode.



**Figure 5.** Relationship between fan speed and current for a 15 mm radius electrode.

and charge induction electrode were placed inside the PVC frame. All plate connections were isolated from the environment. This plate was connected to the earth potential via a Digital Multimeter SC-7403. The contact of charge droplets onto the aluminum plate and transfer of the charge to the earth caused an electrical current in line direction which was detected by a microampere meter (Figure 1).

The tests were carried out first for constant flow rate of  $25 \text{ cc min}^{-1}$  and various levels of voltages, fan speeds, electrode radiuses and horizontal distances between the electrode surface and nozzle tip. Then, the tests were performed for three levels of liquid flow rates, four levels of voltages and six levels of fan speeds for evaluation of the liquid flow rate effect on droplet charging quantity. Various states of fan speeds and generated air speeds are shown in Table 1.

The present study considers a specially designed electrostatic sprayer with ultrasonic nozzle (Figure 2), considering the quantity of droplet charge and the parameters affecting it (Mostafaei, 2006). This research involves evaluation of the charge quantity of droplets and specific charge (charge to mass ratio) of the spray cloud under the application of different voltage levels, air flow speeds, radius of ring electrodes, horizontal distances between electrode surface and nozzle tip and liquid flow rates. Other effective variables are nozzle type and size, solution composition, and the dimension and configuration of the induction electrode. This research covers the

results of laboratory tests on these variables and the effect of the variables on charging of droplets. Although each variable is discussed separately, it is often impossible to discuss each variable independently of the other variables since they are interrelated.

In this system the ring electrode is an agent for charge induction on the droplets and must accomplish its effect on the pesticide solution before atomization and induce electrical charge on the droplets during fluid rupture time. In this state, generated droplets carry part of the liquid charge in separation time. With the aim of droplet forward propelling and preventing the non-homonymous charge return on the electrode and its wetting, the air flow used was fast.

The voltage applied was within the limits of 1.5 kV to 7 kV; investigation of the voltage is the reason for selection of these limits. The electrode radius was about 10 and 15 mm to study its effect on the quantity of charging. All tests were accomplished inside a closed environment to reduce the effect of environmental factors. These factors included the following levels temperature at  $20^{\circ}\text{C}$ , atmospheric pressure at 674.5 mmHg and relative humidity at 32 percent.

## RESULTS AND DISCUSSION

### Voltage

Figures 3 and 4 show the relationship be-

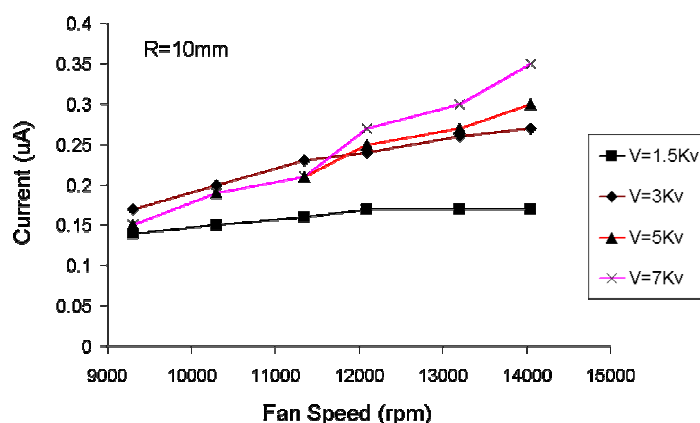


Figure 6. Relationship Between fan speed and current for 10 mm radius of electrode.

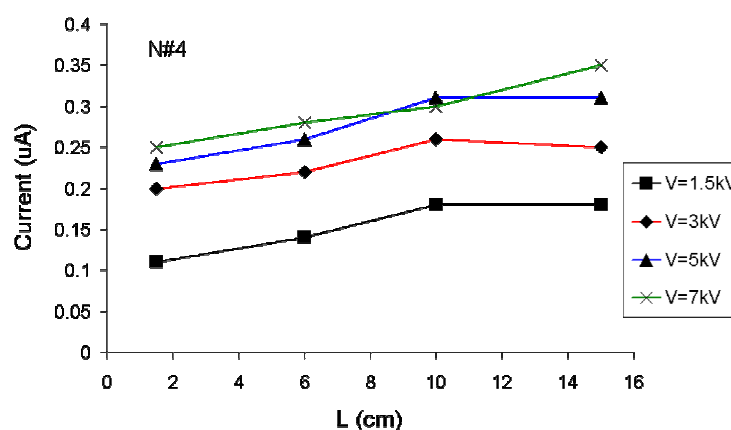


Figure 7. Effect on current of distance between electrode and nozzle tip for R= 15. mm.

tween voltage and current for the same L and different R values and various speeds ranging from 9300 to 14050 rpm. The trend of the curves is almost similar. The results obtained show that, as the voltage on the electrode increases, more charge of the opposite sign to that of the induction surface (electrode) is induced on the droplets generated. The slope of a portion of the curves between 1.5 to 3 kV is greater than that of the other parts for all curves. The quantity of charge which is induced on droplets by increasing the voltage to 3 kV is more than that which can be induced by increasing voltage from 3 to 5 kV or from 5 to 7 kV. The merit of a higher air flow could be a sign for the increased slope of the

N#4, N#5 and N#6 curves.

### Air Flow Speed

Figures 5 and 6 show the relationship between fan speed and current for the same L and different R values and various voltages ranging from 1.5 to 7 kV. Here, also, the trend is similar. The results indicate the role of air flow speed on charging factor. The spray current increased as the airflow is increased. As can be observed from figures 5 and 6, the current obtained through contacting charged droplets onto the aluminum plate increases by increasing the air speed at constant voltages. The amount of increase in cur-

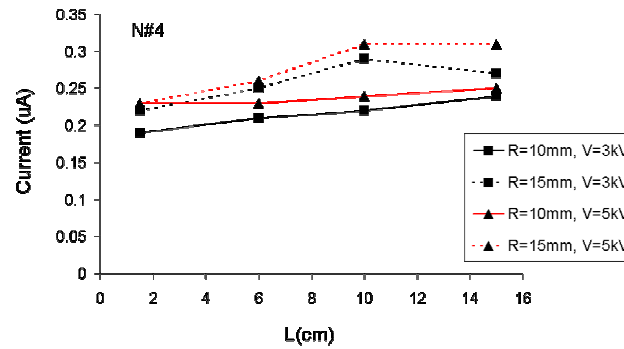


Figure 8. Effect on current of distance between electrode and nozzle tip.

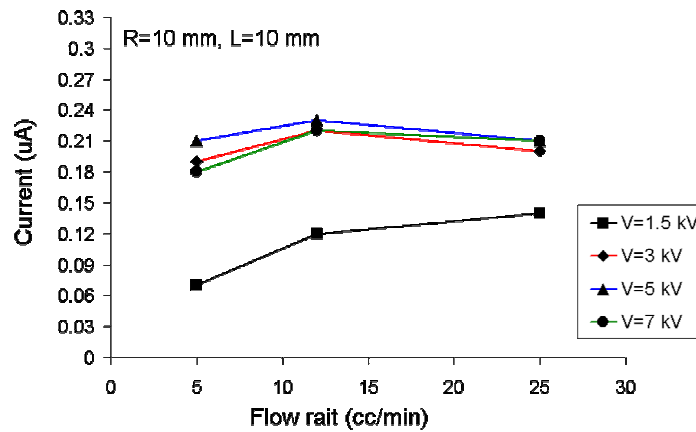


Figure 9. Effect of liquid flow rate on current.

rent with respect to the change in voltage from 1.5 to 3 kV is greater than that obtained from a change in voltage within 3-5 kV or 5-7 kV limits. The charging quantity decreased at higher voltages and at lower air speeds, but the merits of the high air speed compensates this drop in speeds, beyond  $20.2 \text{ m s}^{-1}$ . The charging quantity, therefore, increases again. The electric field associated with the cloud of charged droplets repels the field from the electrode.

### Electrode Radius and Distance from Nozzle

The horizontal distance between electrode and nozzle ( $L$ ) is changed by displacing the

PVC electrode carrier for evaluating the effect of this distance on the quantity of charging, using a fan speed of N#4 at the different voltage levels of 1.5, 3, 5 and 7 kV. The current was registered at any stage and the results are given in Figure 7. These show that the charging factor increases first and then decreases or remains unchanged with the increasing distance between electrode and nozzle. By increasing the voltage range from 1.5 to 3 kV, the current is changed faster than at other higher voltage levels. In the same manner, reducing the electrode radius and using 3 and 5 kV voltages, the quantity of charging increases as electric field intensity is increased (Figure 8). Increasing current in distance of  $L=10 \text{ mm}$  is clearly visible.

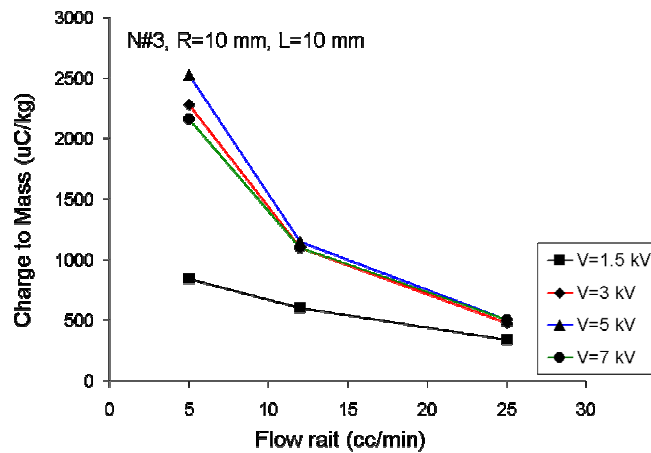


Figure 10. Charge to mass ratio versus flow Rate.

### Liquid Flow Rate

Experimental data were obtained with  $R=10$  mm,  $L=10$  mm and N#3 for the liquid flow rates of 5, 12 and 25  $\text{cc min}^{-1}$ . The related results are shown in Figures 9 and 10. For the 1.5 kV voltage, the charged spray current is increased by increasing the liquid flow rate. At higher voltages, on increasing the liquid flow rate the charged current spray is first increased and then becomes constant or dropping. The reason for this is related to the fact that part of the electric field energy is used for the ionization of liquid droplets which caused the surface of electrode to become wet. In addition to weakening the field, this factor generates droplets in the same sign as that of the induction surface and in the opposite sign to the main droplets. The droplets generated by ionization phenomena come in contact with the main droplets coming out of the ultrasonic nozzle, thus causing a decrease in the current. In Figure 9 the curve related to 7 kV is lower than that of related to 5 kV.

For the aforementioned conditions the calculated charge to mass ratio gives different results. As shown in Figure 10, the ratio of charge to mass at all voltage levels decreases with an increasing flow rate (Dante and Gupta, 1991). The number of droplets generated at a flow rate of 25  $\text{ml min}^{-1}$  is much

higher than that produced at lower flow rates. So, the quantity of charge that induces on any droplet in this specific flow rate will be less. In the airflow of N#3, due to the ionization of air and liquid around the electrode, the charge to mass ratio curve related to 7 kV is reduced with increased liquid flow rate; this is less than that related to 5 kV and also somewhat less than with 3 kV.

### CONCLUSIONS

In this study the effect of any electrostatic induction parameters on droplet charging was investigated. The results obtained show that, as the voltage on the electrode increases, more charge of the opposite sign to that of the induction surface (electrode) is induced on the droplets generated. The slope of a portion of the curves between 1.5 to 3 kV is greater than that for the other parts for all curves. The reason for droplet charge at the higher voltage and lower air speed is the generation of a corona between the induction surface and nozzle body (Franz *et al.*, 1989; Jahannama *et al.*, 2005; Dante and Gupta, 1991). Higher voltages increase the corona generation of air particles and, in this state, the quantity of droplet charging is reduced. The voltage at which the electric arc occurs between the induction surface and the nozzle depends upon the size of the air gap between the induction surface and the nozzle, the airflow and con-



ductivity of the liquid being sprayed (Carroz and Keller, 1978). Such an explanation could be also given for an electrode with a smaller radius and closest distance to nozzle severely.

As the air flow speed increases, the charged spray moves away faster, from the nozzle diminishing this repelling field and allowing a higher spray current. In other words, the surface of droplets that passes in front of the electrode, increases the constant flow rate by increasing air flow speed. Therefore the relaxation time may be decreased and its effect appears on the charge induction of the liquid surface.

With an increasing liquid flow rate, the charged current spray is first increased and then starts dropping; the reason for this is related to ionization phenomena. Because of the increment in the relative number of droplets and weakening of the field through wetness of the electrode for liquid flow rates of between 12 to 25 ml min<sup>-1</sup>, the quantity of induced charge on droplets decreases and the graph slope at this limit will thus be low. The optimum combination of independent parameters is therefore found to be as follows: Q= 5 ml min<sup>-1</sup>, V= 3 kV, L= 10 mm, N# 4, and R= 15 mm.

### Nomenclature

L=	Horizontal distance between electrode and nozzle tip (mm)
N# no=	State of fan speed (according to table)
Q=	Liquid flow rate (ml min <sup>-1</sup> )
R=	Radius of electrode (mm)
V=	Applied voltage (kV)

### REFERENCES

1. Bailey, A. G. 1986. The Theory and Practice of Electrostatic Spraying, *Atomization Spray Technol.*, **2**: 95-134.
2. Carroz, J. W. and Keller, P. N. 1978. Electrostatic Induction Parameters to Attain Maximum Spray Charge, *Trans. ASAE*, **21**: 63-69.
3. Coffee, R. A. 1981. Electrodynamic Crop Spraying, *Outlook Agric.*, **10**: 350-356.
4. Dante, E. T. and Gupta, C. P. 1991. Deposition Studies of an Electrostatic Spraying Disk Sprayer, *Trans. ASAE*, **34(5)**: 1927-1934.
5. Elmoursi, A. A. 1992. Electrical Characterization of Bell-type Electrostatic Painting Systems, *IEEE Trans.*, **IA-28(5)**: 1174-1181.
6. Franz, E., Reichard, D. L., Carpenter, T. G. and Brazee, R. D. 1987. Deposition and Effectiveness of Charged Sprays for Pest Control, *Trans. ASAE*, **30 (1)**: 50-55.
7. Hilsop E. C., Brent, K. J. and Atkins, R. K. 1987. *Requirements for Effective and Efficient Pesticide Application, Rationale Pesticide Use*. Cambridge University Press, U.K., pp. 53-71.
8. Jahannama, M. R., Watkins, A. P. and Yule, A. J. 2005. Electrostatic Effects on Agricultural Air-atomized Sprays and Deposition, Part I: An Experimental Study. *Atomization Sprays*, **15**: 603-628
9. Jahannama, M. R., Watkins, A. P. and Yule, A. J. 1999. Examination of Electrostatically Charged Sprayer for Agricultural Spraying Application, *7ILASS-Europe'99*, Toulouse 5-7th July.
10. Laryea, G. N. and No, S. Y. 2005. Effect of Fan Speed and Electrostatic Charge on Deposition of Orchard Canopy Sprays, *Atomization Sprays*, **15**: 133-144.
11. Laryea, G. N. and No, S. Y. 2004. Electrostatic Spray and Atomization for Agricultural Applications, *Atomization*, **14**: 33-53.
12. Law, S. E. 2001. Agricultural Electrostatic Spray Application: A Review of Significant Research and Development during the 20<sup>th</sup> Century, *J. Electrostatics*, **51-52**: 25-42.
13. Law, S. E. and Scher, H. B. 1984. *Physical Properties Determining Chargeability of Pesticide Sprays, Advances in Pesticide Formulation Technology*, American Chemical Society, Monograph Series No. 254, 219-230,
14. Law, S. E. 1978. Embedded-electrode Electrostatic-induction Spray-charging Nozzle: Theoretical and Engineering Design, *Trans. ASAE*, **21(6)**: 1096-1104.
15. Marchant, J. A. 1985. An Electrostatic Spinning Disc Atomiser, *Trans. ASAE*, **28**: 386-392.



16. Matthews, G. A. 1992. *Pesticide Application Methods*, 2nd Ed., Longman Singapore Publishers (Pte) Ltd, Singapore,
17. Mostafaei, B. A. 2006. Design, Development and Evaluation of a Greenhouse Electrostatic Sprayer, Unpublished MSc. Dissertation in Mechanical Engineering of Farm Machinery, Tarbiat Modares University. Tehran, Iran.
18. Zhao, S., Castle, G. S. P. and Adamiak, K. 2005. The Effect of Space Charge on the Performance of an Electrostatic Induction Charging Spray Nozzle, *J. Electrostat*, **63**: 261–272.

## تأثیر پارامترهای القای الکترواستاتیکی بر باردارسازی قطرات جهت کاربردهای کشاورزی

ب. مصطفایی مینق، ب. قبادیان، م. ر. جهان نما و ت. توکلی هاشجین

### چکیده

در این مطالعه، دستگاه سمپاش الکترواستاتیکی که قبلاً طراحی و ساخته شده است از نظر میزان باردار کردن قطرات مورد ارزیابی قرار گرفت. در این سیستم ذره پاشی مایع به کمک افشانک فراصوتی با حداکثر دبی ۲۵ میلی لیتر در دقیقه و فرکانس نوسانی در حدود ۳۰ کیلو هرتز انجام گرفت. برای باردار کردن قطرات خروجی، از روش القایی استفاده شد. تمام آزمایشها در یک فضای بسته، با دما و رطوبت ثابت انجام گرفت تا از تأثیر عوامل محیطی بر روی نتایج کاسته شود. طی آزمایشها تأثیر ولتاژ در چهار سطح ۱/۵، ۳، ۵ و ۷ کیلو ولت، سرعت جریان هوا در شش سطح ۱۴، ۱۴/۹، ۱۷، ۲۰/۲، ۲۱/۶ و ۲۳ متر در ثانیه، شعاع حلقه باردار کننده در دو سطح ۱۰ و ۱۵ میلی متر و فاصله افقی الکتروود از نوک افشانک در چهار سطح ۱/۵، ۶، ۱۰، ۱۵ میلی متر و دبی در سه سطح ۵، ۱۲ و ۲۵ میلی لیتر در دقیقه بر روی میزان باردار کردن قطرات سم مورد ارزیابی قرار گرفت. حداکثر بارداری قطرات در دبی ۵ میلی لیتر در دقیقه، ولتاژ ۷ کیلو ولت و به ازای سرعت باد ۲۳ متر در ثانیه اتفاق افتاده و جریان الکتریکی حاصل از آن در حدود ۰/۲۴ میکرو آمپر است. با تقسیم جریان الکتریکی به دبی مایع و تبدیل واحدها نسبت بار به جرم قطرات به طور میانگین  $1/0.32 \mu\text{C g}^{-1}$  می باشد. افزایش ولتاژ تا حدودی میزان باردار کردن قطرات را افزایش می دهد ولی در سرعت های پایین جریان هوا بار قطرات در ولتاژهای بالاتر کاهش می یابد. تأثیر جریان سریع هوا بر پدیده بارداری قطرات مثبت بوده و شعاع کوچکتر حلقه باعث القای بار کمتری بر روی قطرات می شود. همچنین با فاصله گرفتن الکتروود حلقوی از افشانک، میزان بارداری قطرات ابتدا افزایش و سپس کاهش پیدا کرده و یا ثابت می ماند.