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Studies on chargeability parameters of charged spray droplets for chemical application in agriculture

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ABSTRACT

The paper describes a method for charging spray droplets for pesticide application in agriculture. An induction based electrostatic charging system was developed with optimized parameter namely flow rate, electrode voltage and distance of electrode from nozzle tip. A high voltage charging module was fabricated to supply the voltage up to 10 kV. The experiments were conducted in division of agricultural engineering, IARI, New Delhi during 2017. A faraday cylinder test rig was used to optimize the flow rate, electrode voltage and distance of electrode from nozzle tip. The highest charge to mass of 1.543 mC/kg was obtained at a flow rate of 450 ml/min, applied voltage of 4.0 kV and electrode distance of 40 mm respectively. The results of CMR established the relationship between CMR and selected design parameters. The statistical analysis revealed that the individual effect of selected parameter had significant effect on CMR at 1% level of significance, whereas the interaction effect of voltage, flow rate and electrode position from nozzle tip had no significant effect on CMR.

Key words: Electrode voltage, Electrostatic spray, Faraday cylinder

In India, the crop losses due to insect pest range from 5% in wheat to as high as 30% in cotton with an estimate annual loss of ₹237 billion for all the crops taken together. The increased damage to crops from pests and subsequent losses poses a serious threat to food security (Sushil 2016). The chemical methods for control of insects and pests play a major role in agricultural production system by reducing the potential yield loss and, thus, increasing the productivity (Freedonia World Pesticide forecast 2014; Maski and Durairaj 2010).In India, pesticide application techniques are still traditional high volume spraying with larger spray droplets that lead to wastage of agricultural chemicals and ensuing environmental concern due to off target deposition of chemicals (Babu *et al.* 1990).The potential risk involved in excessive use of chemicals in agricultural production system has forced the researchers around the world to develop new and powerful methodologies to control pests, diseases, insects and weeds present in the agricultural fields (Edward 2010; Jia *et al.* 2013). Uniform droplet distribution on canopy and abaxial deposition of spray droplets is a major challenge in spray application methods practised in India. Electrostatic charging of spray chemicals can be a viable option to mitigate the above problems. The electrostatic spraying technology enhances the spray distribution, increased uniformity and better transfer of spray particle at the intended target (Jyoti *et al* 2017; Jyoti *et.al* 2019) .

There are different methods for charging the spray droplets emerging out of the nozzles (Kang *et al.* 2007). In electrostatic charging, the formation of droplets and reception of charge on the droplets emerging out of the nozzle depends on the electrical and mechanical properties of spray liquid (Al-Mamury 2015; Jyoti *et al.* 2017; Jyoti *et al.* 2019). The design of a induction based electrostatic charging system requires optimization of application voltage, electrode position and flow rate to achieve maximum CMR, which is the measure charge attained per unit mass of the droplet. Therefore, the study was conducted to develop a spray charging system for charging pesticide droplets to achieve maximum bio-efficacy.

MATERIALS AND METHODS

A laboratory Faraday cylinder test rig was developed to measure CMR of the spray droplets (Fig 1). The spray charging system mainly comprised of a hydraulic nozzle, droplet charging electrode, high voltage multiplying circuit and high voltage probe.

The hydraulic hollow cone nozzle was selected for its low air pressure requirement, economic feasibility and ease of commercial availability in local market. The charge imparted to the droplet depends on the conductivity of electrode material. Hence, copper was selected as electrode material as it is economical and readily available compared to other electrode material and possesses higher CMR at lower voltage potential. An induction based electrode made

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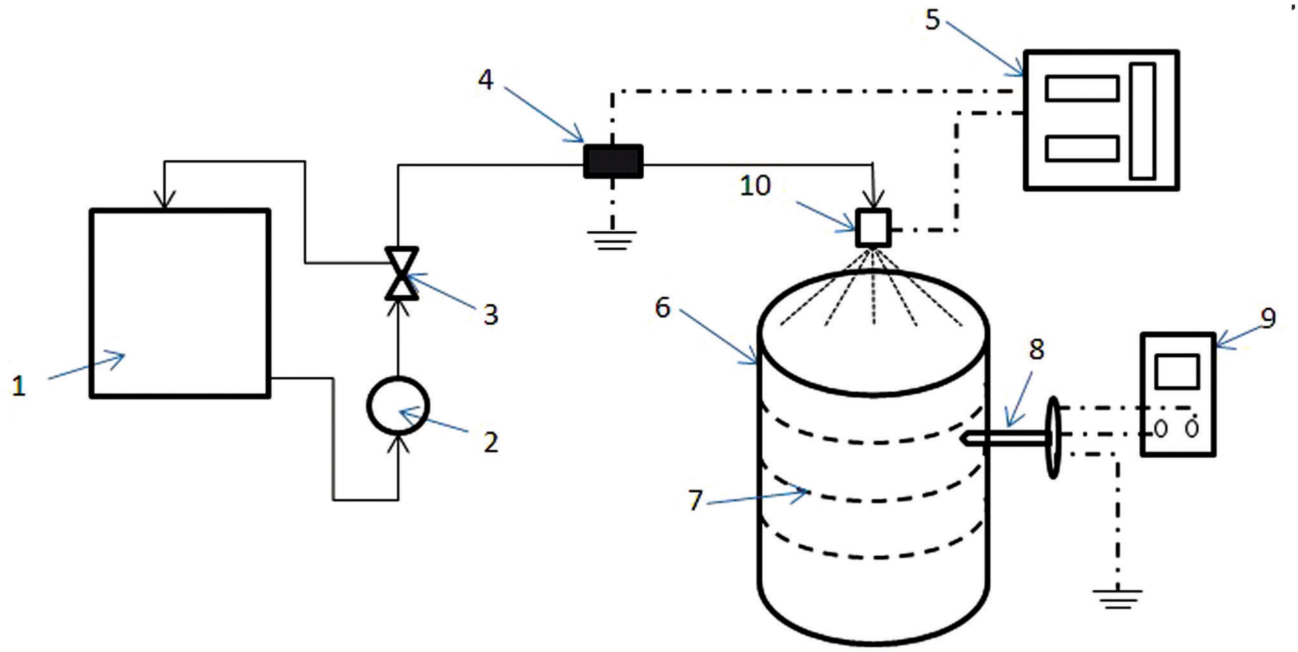

Fig 1 Faraday cylinder test rig for measurement of CMR. 1. Tank, 2. Hydraulic pump, 3. Pressure Regulating Valve (PRV), 4. Butterfly valve, 5. High voltage multiplying circuit (HVC), 6. Faraday cylinder, 7. Aluminum wires mesh, 8. High voltage probe (HVP), 9. Multimeter, 10. Induction nozzle.

of copper was placed co-axially with the nozzle at spray cone angle of 80 degree. A high voltage module was fabricated to deliver voltage up to 7.5 kV to impart charge to the spray droplets emerging out of the hydraulic nozzle. Many commercial imported high voltage modules were available in the market but these modules were very expensive to be used in Indian farm conditions. Therefore, the circuit made up of a high tension coil (5 Amps through the 8 mH primary inductance) was developed to generate voltage up to 10 kV and tested for its loading characteristics. The high voltage generator consists of a high tension coil, ATMEGA 18 microcontroller, IRFZ44N Mosfet, LM016L LCD screen, 1 k resistor, 130 pf capacitors and push buttons to input selected levels of voltages by varying the width of input pulse controlled through the microcontroller. A high voltage probe with an attenuation factor of 1:1000 was connected in conjunction with the multi-meter to determine the spray cloud current and high output voltage on the electrode.

The high CMR of charged droplets is a function of flow rate of nozzle, electrode position and electrode voltage (Maski and Durairaj 2010, Maynagh 2009, Marchant and Green 1982). Hence, it is important to these parameters for significant energy savings and increased charge mass ratio of spray droplets. The parameters selected for the design of induction based spray charging system is shown in Table 1.

To measure the static–charge accumulated on the spray droplet during electrostatic charging, a Faraday's cage technique (Marchant and Green 1982, Wilson 1982, Marchant *et al.* 1985, Law and cooper 1987, Dante and Gupta 1990) was adopted. The Faraday's cylinder was developed to transfer all the charged spray fluid at any instant of time and, thereby, to acquire all the charge carried by the fluid. The charge carried by the spray droplets was transferred to the conductive body of the cage.

Table 1 Design parameters considered for induction nozzle

Independent parameters	Levels (Values)	Dependent parameters
Flow rate of nozzle (Q)	250, 450 and 600 ml/min	CMR, mC/kg
Distance of electrode from nozzle orifice, D	20 , 40 and 60 mm	
Electrode voltage, V	2.5, 4.0 and 7.5 kV	

The Faraday cage was a hollow cylindrical drum made up of 16 gauge aluminium sheet having 900 mm length and 600 mm diameter. Three circular sieves made of 1 mm stainless steel were provided at equal intervals from its bottom up to half the total length of the cage. The mesh was provided to capture all the spray charge and transmit it to the conducting body of the cage. The transfer of charge to the cage was completed by allowing the spray liquid to have more contact area with the conducting mesh. A tap was provided at the bottom to facilitate draining of the spray liquid whenever necessary. The Faraday cylinder was kept on Bakelite sheet placed on the wooden block to electrically insulate it from ground.

The experiments were conducted in division of agricultural engineering, IARI, New Delhi during 2017 for selected levels of flow rate, electrode position and electrode voltage. The spray nozzle system was calibrated with each selected nozzle to get desired flow rate at selected pressure of 413685 N/m^2 (60 psi). As the droplet come out of nozzle, charge transfer results from the electrostatic induction of electrons onto the axial jet in order to maintain it at ground potential in the presence of the nearby charged cylindrical electrode. Individual droplet formed from this negatively charged continuous jet departed with a net negative charge provided that the droplet-formation zone between nozzle and cylindrical electrode was subjected to the inducing electric field acting between the cylinder and the jet. The Faraday cylinder was placed in front of the induction nozzle to collect the charged spray droplets to estimate the charge acquired by spray droplets. The spray cloud current and voltage were recorded by high voltage probe in conjunction with the multi-meter. The voltage and spray cloud current were recorded during each experiment that replicated thrice.

The performance of an electrostatic sprayer was assessed in terms of CMR which indicates the amount of charge obtained per unit mass of the spray droplets. CMR is the most critical factor that influences deposition of spray on the target. It is defined as the ratio of charge quantity to mass of droplet deposited (Yaun *et al.* 2000, Jia *et al.* 2008, Wen *et al.* 2003 and Maynagh 2009).

RESULTS AND DISCUSSION

Effect of electrode voltage on charge to mass ratio of spray liquid

Almekinders *et al.* (1992) reported that the voltage significantly affects the chargeability of spray droplets. This relationship was investigated for selected level of 2.5 kV, 4.0 kV and 7.5 kV, respectively. In general, the charge to mass ratio varied linearly from 2.5 to 4.0 kV and later remained constant and showed decreasing trend after 4.0 kV. There was an initial increase of the charge-to mass ratio up to a critical applied voltage and then started decreasing or remained almost constant at a higher applied voltage (Fig 2a). After saturation point of 4.0 kV, the inductive charging tends towards conductive charging, encountered by positive current, which led to decrease in CMR. The highest value of charge to mass ratio of 1.540 mC/kg was obtained at electrode voltage of 4.0 kV corresponding to 250 ml/min of flow rate of and of 40 mm nozzle distance. The CMR of spray droplets for selected flow rates and electrode distance varied from 0.346 – 1.540 mC/kg. It was observed that the CMR of spray droplets varied rapidly with increase in voltage from 2.5 kV to 4.0 kV. The CMR of spray droplets were 0.5470 - 0.6670, 0.4247-0.5510 and 0.3460 - 0.4527 mC/kg at flow rates of 250, 450 and 600 ml/min, respectively.

In general, the CMR increased linearly with increase in applied voltage up to 4.0kV for all selected levels of flow rates, beyond this voltage the response of charge to mass ratio to voltage began to flatten out. This critical value at which flattening occurred was important for study. During experimentation, it was observed that the voltage increased up to 7.5 kV increased the spray charge; further increase in applied voltage decreased the CMR. This was attributed to the fact that after a negative corona – discharge current from liquid jet becomes active, an equal positive current needed to be supplied to the induction electrode in order to neutralize the highly mobile electrons and negative air ions which are drawn to its surface, resulting into surface leakage and a reduction in chargeability thereon (Law 1978, Marchant *et al*. 1985, Machowski and Balachandran 1997).

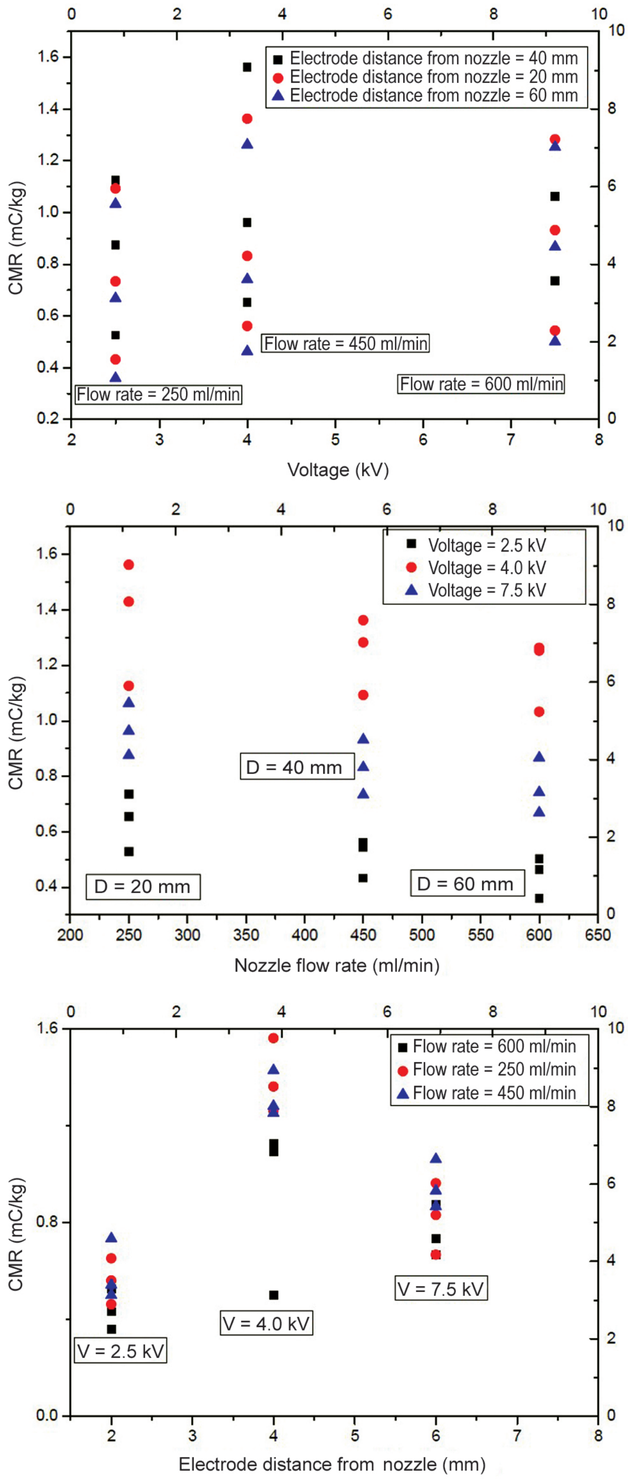

Fig 2 a) Effect of applied voltage, b) Flow rate and c) Electrode distance from nozzle on CMR of spray liquid.

For high charging efficiency, the electrode should be close enough to the liquid film, but if this distance is too small, the droplets are more likely to be attracted to the electrode surface due to Coulomb force. Wetting of the charging electrode should be avoided since this phenomenon leads to deterioration of the atomizer and charging electrode. As the conductivity of liquid changes, the dielectric of air media between electrode and liquid sheet changes and hence the load current changes. Therefore, from the above results it was concluded that though the charge to mass ratio increased from 4.0 to 7.5 kV, the electrode voltage of 4.0 kV was best for design of electrostatic nozzle to avoid negative corona discharge current.

Effect of flow rate on CMR of spray liquid

The charge to mass ratio of spray liquid was affected by flow rate of nozzle. This relationship was investigated for selected level of 250, 450 and 600 ml/min. The observed values of charge to mass ratio for spray droplets were plotted against the selected level of flow rates. The relationship between charge to mass ratio and flow rate are illustrated in Fig 2b.

The rate of decrease in charge to mass ratio of spray liquid was higher for lower flow rates then at the higher flow rates. This led to the conclusion that the charge to mass ratio was affected more at lower flow rate attributed to the fact that at lower flow rate the droplets coming out of the nozzle are finer compared with to droplets formed at higher flow rate. The increase in charge density on the finely atomized droplets was due to large surface area exposed to the applied charging field strength. It was found that the CMR showed a decreasing trend with increase flow rate. The maximum value CMR of 1.540 mC/kg was observed at applied voltage of 4.0 kV and electrode distance of 40 mm. At 40 mm electrode distance the droplet coming out the nozzle did not come in contact with the electrode surface, hence it encountered maximum electric field as there was no wetting effect or shorting. The CMR at electrode distance of 20 mm was minimum as at closer electrode position the charged particles were attracted by the electrode surface due to Coulomb force. This led to conclusion that the CMR was less affected by higher flow rates of spray liquid (Mamury *et al,* 2015).

Effect of distance of electrode from nozzle orifice on CMR of spray liquid

The CMR of spray liquid was affected by the distance of electrode from the nozzle orifice. The charge to mass of spray liquid linearly increased from electrode distance of 20 to 60 mm and then decreased linearly up to 60 mm (Fig 2c). The rate of increase in CMR of spray liquid was 100.9, 130 and 102.0 % from electrode distance of 20, 40 and 60 mm, respectively, whereas the rate of decrease was by 59.5, 49.7 and 50.0 % at selected levels of applied voltage. The maximum and minimum CMR of 1.54 mC/kg and 0.547mC/kg was observed at electrode distance of 40 mm and 20 mm for flow rate of 250 ml/min, respectively.

The charge to mass ratio decreased significantly as the flow rate of spray liquid increased from 450 to 600 ml/min. This was attributed to fact that at higher flow rate the atomization droplets were coarser compared to droplets formed at lower flow rates. In case of the electrode distance at 40 mm all the droplets move toward electrode and gets opposite charge (negative), whereas at 20 mm, they moved away from the electrode and resulted in same charge (positive). Therefore, to achieve maximum CMR, the electrode should be located within the range of atomization which was found to be 40 mm for the designed nozzle.

The observed results were statistically analysed to establish the effect of voltage, flow rate and distance of electrode from nozzle tip on chargeability of spray droplets. The ANOVA revealed that all the three main factors namely voltage, flow rate and distance had significant effect on CMR at one per cent level of significance. It was observed that the interaction effect of voltage and flow rate has no significant effect on CMR. The CMR of spray droplets were significantly different at voltages above 4.0 kV and discharge of spray liquid above 450 ml/min. This implies that the influence of larger discharge on chargeability was a factor to contend with higher voltages.

The ANOVA for quadratic model revealed highly significant model ($P<0.01$) for predicting CMR. The effect of interactive terms had no significant effect on the CMR of spray liquid, this was attributed to fact that all the effect of all main factors on CMR were inversely related. The model had adjusted R-square 0.98 due to others non-significant interactive terms of the model.

Conclusions

The study was conducted to design an induction based spray charging system for pesticide application in agricultural fields. A hydraulic nozzle with coaxially placed copper electrode connected to a microcontroller based high voltage generator was fabricated. The design parameters like flow rate (250, 450 and 600 ml/min), voltage (2.5, 4.0and 7.5kV) and distance of nozzle from orifice (20, 40 and 60 mm) were analysed in terms of charge mass ratio in Faraday cylinder experimental set up. The CMR values with varying applied voltage for corresponding flow rate and distance from electrode varied from 0.346 – 1.540 mC/kg. The CMR was seen to increase linearly with increase in applied voltage for all selected levels of flow rates, after which the response of CMR to voltage began to flatten out. This critical value at which flattening occurred was 4.0 kV. The maximum and minimum CMR was 1.54 mC/kg and 0.547 mC/kg was observed at electrode distance of 40 mm and 20 mm for flow rate of 250 ml/min, respectively. All the experiments was conducted in laboratory condition, hence further study may be conducted to assess CMR in outdoor environmental conditions.

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