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Optimization of Design Parameters of Electrostatic Induction Nozzle

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ABSTRACT

The electrostatic induction mechanism, which superimposes charges on pesticide spray droplets, is critical for plant protection. It has an impact on the properties of spray droplets, as well as their deposition and wraparound effect on leaf surfaces. As a result, using the optimal parameter combination will enhance spraying efficiency while reducing pesticide waste and toxicity. The charge to mass ratio (CMR) has a huge effect on deposition and the wraparound effect on the leaf surface. The effect of 0-6 kV applied voltages, flow rates of 230, 450 and 650 ml min^{-1} and electrode placement from nozzles of 0, 15, and 30 mm were studied in this study, with all other parameters kept constant. A faraday test rig was developed to measure accumulated spray charge. The combined parameters of 6 kV applied voltage, 230 ml min^{-1} and electrode placement of 15 mm produced maximum charge to mass ratio.

Keywords Charge to mass ratio, CMR, Electrostatic induction nozzle, Spraying, Faraday cage.

INTRODUCTION

Neglecting pest control completely can result in a yield loss of up to 57%, while avoiding soil pests, foliar diseases, and foliar insects can reduce yield by 27%, 32% and 37%, respectively in groundnut (Tanzubil and Yahaya 2017). The pesticide application technique is critical for precisely directing the amount and quality of sprays on crops for cost-effective and ecologically friendly insect control. Pesticide costs are rising, and environmental concerns are growing, necessitating increased efficiency in pesticide spray treatments for crop protection (Gu *et al*. 2015). The use of charged sprays might reduce the massive waste of chemicals and the resulting pollution caused by off-target deposition of traditionally sprayed insecticides. Electrostatically charged sprays for agricultural use may give better droplet control, better overall deposition, and dispersion, and so lower the amount of spray chemicals used. Because electrostatic forces on tiny droplets are stronger than gravity forces, electrostatic charge of spray droplets

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mostly results in leaf deposition on the underside. The "wrap-around" effect of electrostatically charged sprays has been shown to promote the underside leaf (abaxial) deposition (Edward Law 2001, Marchewicz *et al.* 2019). Insects and pests that live in protected sections of the plant (under the leaf) may be destroyed by precisely placing pesticide droplets for cost-effective pest management (Maski *et al.* 2004). Furthermore, better deposition, dispersion, and penetration of charged spray into the plant canopy may significantly boost biological efficacy.

The electrostatic spraying method improves spray dispersion, homogeneity, and spray particle transfer to the desired target (Jyoti and Mani 2020). The spray droplets emanating from the nozzles may be charged in a variety of ways (Kang *et al.* 2007). The CMR, which is the measure charge acquired per unit mass of the spray, charged spay quantifiably influences the deposition characteristics of the sprayer (Mamidi *et al.* 2013, Marchewicz *et al.* 2019). In this present study, optimizing the independent variables (i.e., application voltage, electrode location, and flow velocity) in order to get maximum CMR.

MATERIALS AND METHODS

Electrostatic induction spray charging system

The electrostatic induction spray charging technique was chosen for this investigation because of its recognized benefits over other charging methods, such as high charge transferability, lower risk of life and ease of fabrication. The system comprises of a spray nozzle and an electrode arranged concentrically with the spray nozzle in the region of the spray atomization zone. An electrostatic field will be formed around the charging electrode when a suitably high voltage direct current (DC) is given to it and the spray liquid is grounded. The electrode is locked in place so that it is exposed to the largest spray atomization area possible (Fig. 1). The maximum droplet charging happens

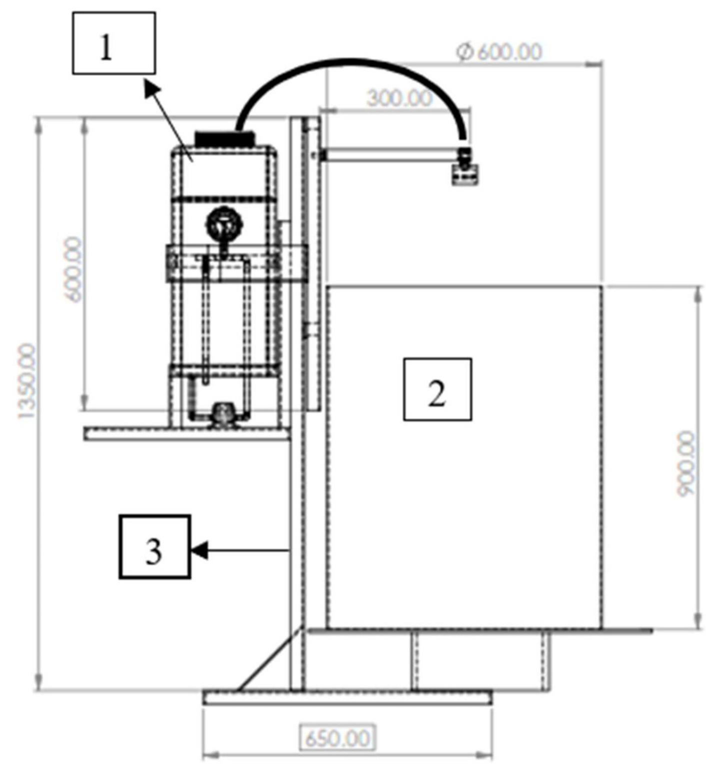

Fig. 1. Schematic diagram of developed experimental setup (1. Sprayer setup, 2. Faraday cage and 3. Main frame).

Table 1. Analysis of variance of design factors on CMR.

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Model	26	13.91	0.54	421.54	0.00	99.51
Linear	6	13.57	2.26	1782.44	0.00	97.10
Voltage (kV)	2	1.96	0.98	771.61	0.00	14.01
Flow rate (ml/min)	2	11.44	5.72	4505.10	0.00	81.81
Electrode position (cm)	2	0.18	0.09	70.62	0.00	1.28
2-Way interactions	12	0.32	0.03	20.68	0.00	2.25
Voltage (kV)*Flow rate (ml/min)	4	0.22	0.06	43.60	0.00	1.58
Voltage (kV)*Electrode position (cm)	4	0.01	0.00	0.99	0.42	0.04
Flow rate (ml/min)* Electrode position (cm)	4	0.09	0.02	17.47	0.00	0.63
3-Way interactions	8	0.02	0.00	2.14	0.05	0.16
Voltage (kV)*Flow rate (ml/min)*Electrode position (cm)	8	0.02	0.00	2.14	0.05	0.16
Error	54	0.07	0.00			0.49
Total	80	13.98				

when the droplet formation zone is exposed to the maximum field strength (Law 1978, Mamidi *et al.* 2013). As a result, any liquid with a nonzero electrical conductivity will build an excess image charge on the grounded spray liquid with the opposite polarity.

Development of experimental setup

The developed experimental setup consists of main frame, faraday cage and sprayer setup. Main frame was MS frame for mounting of various components such sprayer setup and faraday cage. Sprayer setup consist of tank, DC motor pump, hose pipes, nozzle and high-voltage generation circuit. High voltage module E70 used to develop the high voltage generation circuit. The circuit provides a maximum voltage of 7 kV and output voltage of the high voltage module varies with the input voltage (0 to 15V). The faraday cylinder was a hollow cylindrical drum made of a 16-gauge aluminum sheet with a diameter of 600 m and a height of 900 mm (Law and Cooper 1987, Marchant and Green 1982, Marchewicz *et al.* 2019).

Experimental procedure for determination of CMR

The spray lance was firmly clamped at center of main frame along with the induction nozzle. The faraday cylinder was mounted on acrylic sheet, which was placed above the wooden block to electrically insulate it from ground (Fig. 1). A total number of 81 randomly replicated experiments were conducted with selected levels of flow rate (230, 450 and 650 ml min^{-1}), electrode position (0, 15 and 30 mm) and electrode voltage (2.0, 4.0 and 6.0 kV). Before conducting trails with each treatment, the spray nozzle system was calibrated with each selected nozzle to get desired flow rate at selected pressure of 400 kpa. Net negative charged were produced providing droplet formation zones between the nozzles. It was due to the individual droplets formed and departed from the negatively charged continuous jet. Also, cylindrical electrode was subjected to the inducing electric field acting between the cylinder and the jet. The spray cloud current and voltage were recorded by high voltage probe inserted onto the faraday cylinder in conjunction with the multimeter. Each experiment was replicated thrice and the voltage and spray cloud current were recorded. The experiment was repeated for all combination levels of flow rate, electrode position and voltage.

Table 1 lists the design factors that were examined for this investigation, as well as their levels. The experiment was carried out with ground water. Using the minitab. 21 software program, a complete factorial design was built. To assess the influence of various design characteristics on CMR, 81 experiments (33*3) were undertaken in total. For each run, design parameters such as flow rate, applied voltage, and electrode placement were adjusted as per design.

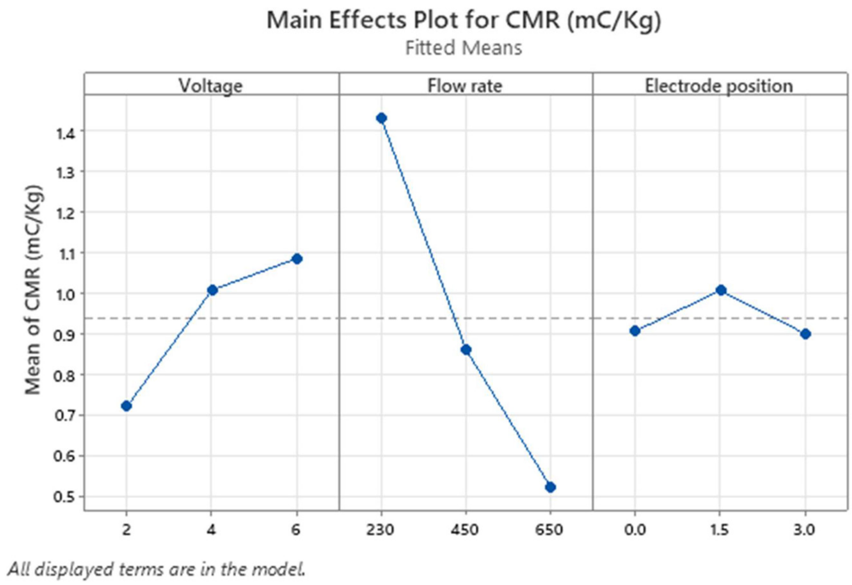

Fig. 2. Graph showing effect of design parameters on CMR.

To obtain the selected flow rates three hollow cone nozzles was selected (Lechler TR80-0.05, TR80-0.01 and TR80-0.015), All the experiments was conducted at a pressure 400 kpa make uniformity in spray distribution.

RESULTS AND DISCUSSION

Analysis of variance of CMR

Minitab software was used to generate an analysis of

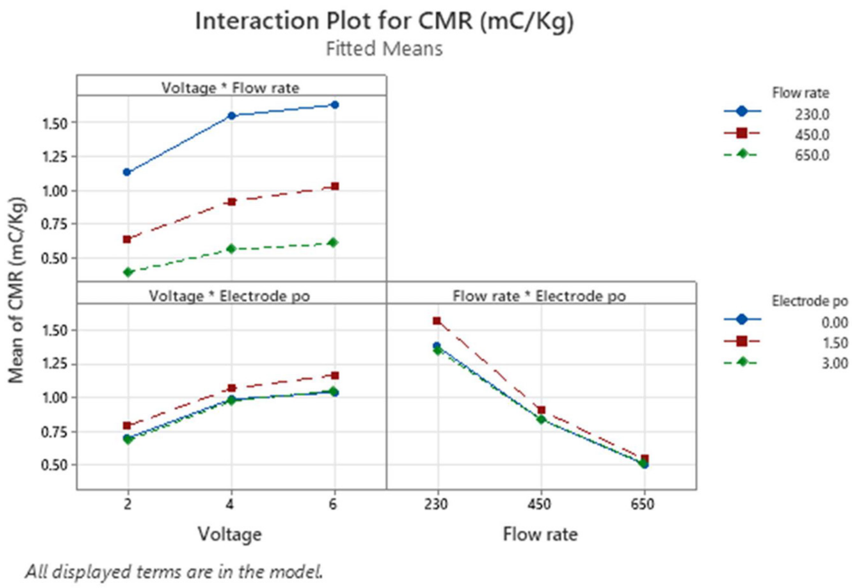

Fig. 3. Graph showing interaction effects of design parameters on CMR.

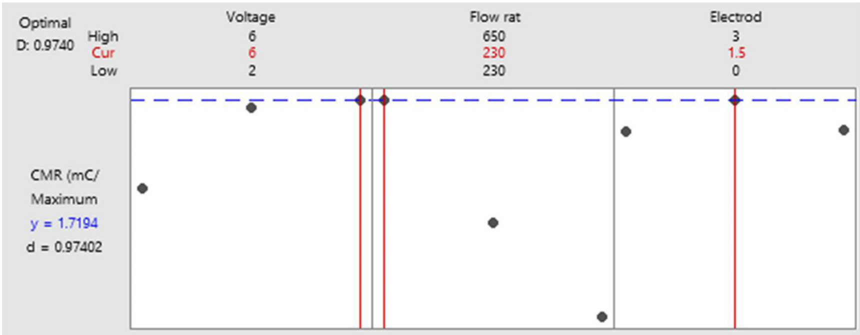

Fig. 4. Optimization plot for effective swath width.

variance table that took into account the general full factorial design. Table 1 shows the ANOVA table for CMR. The main effects of each component, 2-way interaction effects, and 3-way interaction effects are all significant at the 5% level of significance, as shown in the ANOVA table. The overall F-test was also found to be significant at the 5% level, implying that the model as a whole account for a large percentage of the variability in the dependent variable. ANOVA identifies the design parameter that has the greatest impact on performance. CMR is highly impacted by flow rate, followed by gap between applied voltage and electrode location, according to the ANOVA table. The percentage contribution of flow rate, applied voltage and electrode placement was 81.81%, 14.01% and 1.28% respectively.

Effect of design parameters on CMR

The effect of design parameters on CMR was shown in Fig. 2. It is observed that CMR increased with increase in applied voltage. It is also observed that CMR decreases with increase in flow rate, as the electrode position CMR also increased up to certain level and a further increase in electrode position decrease in

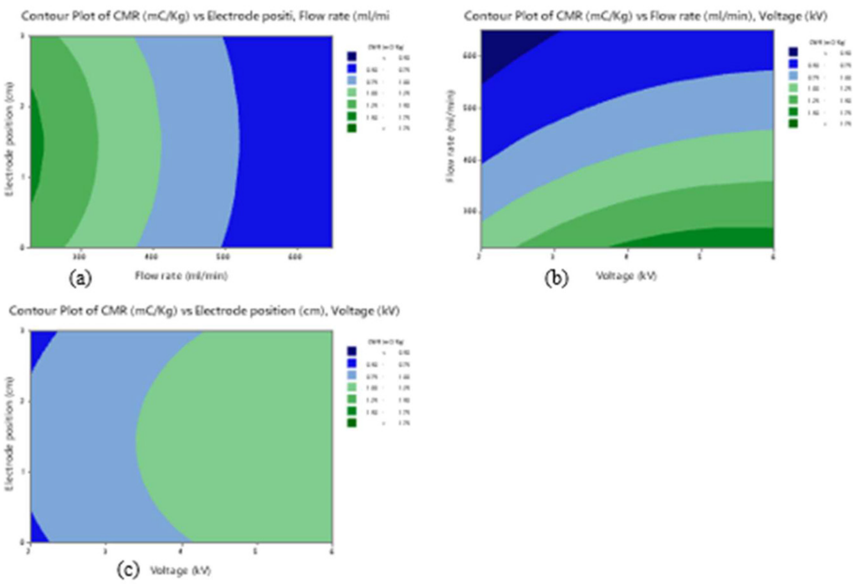

Fig. 5. Contour plots of CMR (a) flow rate Vs electrode position (b) voltage Vs flow rate (c) electrode position Vs voltage.

Table 2. Optimized solutions obtained from analysis.

Solution	Voltage (kV)	Flow rate (ml/min)	Electrode position (cm)	CMR (mC/kg) fit	Composite desirability
1	6	230	1.5	1.71940	0.974018
2	4	230	1.5	1.68047	0.945920
3	6	230	3	1.57067	0.866676

CMR, similar kind of results reported by (Mamidi *et al.* 2013). Trend of interaction effects on CMR is shown in Fig. 3. From interaction effects graph, it is observed that applied voltage increases CMR for all flow rates, however more swath width was observed at 230 ml/min. For flow rates, CMR shows a decreasing trend with increasing flow rates for all electrode positions, however more CMR observe for 15mm electrode position, similar kind of results reported by (Patel *et al.* 2016). Given interaction effects graph is self-explanatory, the other interaction effects on CMR can examine from the given graph.

Optimization of design parameters for obtaining effective CMR

Fig. 4 shows the optimization plot created using the minitab. 21 software programme. From Table 1, the maximum CMR was obtained when the applied voltage was 6kV, the flow rate was 230 ml min^{-1}, and the electrode location was 15mm. Therefore, the predicted optimum design parameters for obtaining maximum CMR is V = 6kV, Q=230ml min^{-1}, and electrode distance =15 mm. Table 2 shows optimized design parameters. Fig. 5 shows contour plots analysing the relationship between design parameters and CMR. According to Fig. 5(a), a medium electrode location and a low flow rate result in greater CMR. Fig. 5(b) shows that more voltage could be attained at low level of flow rate produces the highest CMR. It is clear from Fig. 5(c) that medium level of electrode placement and high voltage level yields more CMR.

CONCLUSION

The main effects of each factor, 2-way interaction effects and 3-way interaction effects are significant at 5% level of significance. It was also indicated that the overall F-test is significant at 5% level indicating that the model as a whole account for a significant portion of the variability in the dependent variable. The CMR is significantly influenced by flow rate followed by applied voltage and electrode position. The percentage contribution of flow rate followed by applied voltage and electrode position on CMR was 81.81%, 14.01%, and 1.28 % respectively. The optimum combination of design parameters for effective CMR was 230ml min^{-1}, 6 kV and 1.5 mm. The obtained optimum operation combination for CMR significantly improved the performance of spraying activity.

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