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Effect of Electromechanical Properties on Spraying Quality of Electrostatic Sprayer

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Abstract Electrostatic-spraying technology is an emerging spraying technology. Electrostatic charging promotes more spray deposition on the target plants and less deposition on the ground. A detailed study was conducted to predict the effect of water quality and chemical formulation on electromechanically properties which affects the spraying quality of spray liquid for design of electrostatic sprayer. Electromechanical properties of spray liquid effect the droplet formation, terminal velocity, charge mass ratio (CMR) and deposition efficiency required for design of electrostatic sprayer. It was observed the individual effect of dose (D) does not have any significant effect at 5% level of significance. The water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance. The recommended value of electromechanical properties i.e. density (1.0025881–1.0056984 gm cc^{-1}), surface tension (0.06821–0.07201 Nm^{-1}.), dynamic viscosity (0.87155–0.92103 mPa.s), electrical conductivity (563 –1950 µs/cm) and dielectric constant (563 -1950 µs/cm)were suggested to obtained desired CMR to impart charge on spray particle. Therefore tap water and ground water is recommended to determine the coverage and deposition efficiency of electrostaic spayer.

Keywords Electrostatic-spraying, Electromechanical, CMR.

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Introduction

Electrostatic-spraying technology is an emerging spraying system in Asia because of shortage of water, whole canopy coverage, biological efficacy and labor scarcity crisis. Electrostatic charging of atomized droplets of spray particles used in agricultural spraying has several demonstrated advantages compared to conventional spraying application methods, charged spray droplets showed more spray deposition on the target plants and less deposition on the ground [1]. Physical characteristics of charged sprays,

Table 1. Chemicals and different water types used to asses electromechanical properties.

1.	Chemical used	i) Pendathamalin ii) Imidocloprid iii) Metalaxyl iv) Thiamethoxam v) Teidemoph
2.	Water quality	i) Distilled water ii) Tap water iii) Ground water

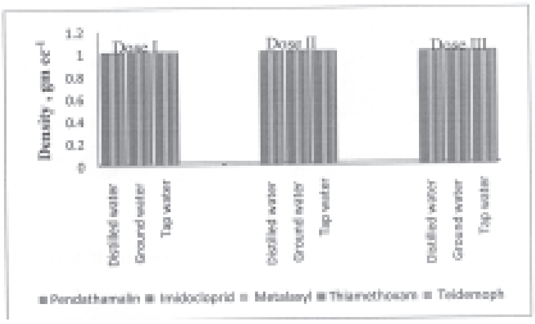

Fig. 1. Effect of doses, water quality and chemical type on density of spray liquid.

such as their predisposition to deposit in the upper regions of the crop canopy, contribute to erratic pest control and canopy penetration. Because most electrostatic charging has been done on naturally atomizing sprays, it has been suggested to use of hydraulic pressure or air assistance to atomize the liquid droplets [2]. Use of electrostatic sprayers has been studied for agricultural application, electrical and physical characteristics of spray particles effects the deposition efficiency and charge carrying capacity of spray droplets [3, 4]. Deposition of charged sprays on leaf abaxial (underside) and adaxial (upper) surfaces as influenced by the spray charging voltage, application speed, target height and orientation parameters was studied in the laboratory [5]. Electrostatic spraying of pesticides was not successfully commercialized because of less penetration in to the crop canopy although the charge on small droplets was effective, which increased deposition and reduced downwind drift [6, 7]. In water-based sprays, the density is more or less constant for different concentration of the pesticide solution. Since the deposition of spray on leaf surface depends on the electromechanical properties of spray liquid [8, 9], hence an extensive study was conducted to assess the effects of water quality and chemical with varying doses on electromechanical properties of spray liquids.

Materials and Methods

A detailed study was conducted to predict the effect of water quality and chemical formulation on electromechanically properties which affects the spraying quality of spray liquid for design of electrostatic sprayer. For this study four common water soluble chemicals frequently used in field with varying doses were used with different water quality to estimate the electromechanical properties of spray liquids (Table 1). Droplet formation and subsequent impregnation of charge into the droplet is a complex phenomenon involving both the electrical and mechanical properties of fluid being charged. Any study on the chargeability of droplets and deposition on the target, should hence consider the effect of spray on this performance. Towards characterizing the spray fluids being tested on the experimental charging system, there was a need to assess the characteristics of the spray fluid (in our case, the type of water used) in terms of electrical and mechanical properties.

Assessment of mechanical properties

Mechanical properties such as density, dynamic viscosity and surface tension spray liquids have direct or indirect effect on the formation of droplets and in turn affect their transportation and biological effectiveness [10].

These three properties can be related to the droplet diameter in a functional form as.

$$d_d = f(\rho_1, \eta_2, \sigma)$$

Where, d_d = is the droplet diameter, ρ_1 = is the density of spray liquid, kg m^{-3}, η_2 = is the dynamic viscosity of the liquid, Ns m^{-2}, σ = is the surface tension of the liquid, Nm^{-1}, This droplet diameter in turn influences electrostatic chargeability of the spray.

Table 2. Anova table for effect on density with changes on doses, water quality and type of chemicals. a. *R* Squared = .999 (Adjusted *R* Squared = .999).

Source	Type III sum of squares	Degree of freedom	Mean square	*F*	Sig.
Corrected model	0.001[a]	44	1.755E-5	2787.391	0.000
Intercept	135.713	1	135.713	2.155E10	0.000
DOSE	0.000	2	0.000	0.000	1.000
Water quality (WQ)	0.001	2	0.000	61183.967	0.000
Chemical (C)	8.342E-7	4	2.086E-7	33.124	0.000
DOSE * WQ	0.000	4	0.000	0.000	1.000
DOSE * C	2.013E-9	8	2.516E-10	0.040	1.000
WQ * C	9.059E-7	8	1.132E-7	17.985	0.000
DOSE * WQ * C	0.000	16	0.000	0.000	1.000
Error	5.667E-7	90	6.296E-9		
Total	135.713	135			
Corrected total	0.001	134			

The above three characteristic properties were evaluated as follows.

Density

Hence it is determined in order to characterize the type of water used as the spray fluid. Procedure adopted for determining the densities of water was to relatively compare its density with that of the density of pure distilled water. A beaker and an electronic balance were used for this purpose. Initially the mass of the empty beaker (W_1) was measured using an electronic balance. Pure distilled water filled up to the brim of the breaker. The water filled beaker was weighed by using the eletronic balance and its mass (W_2) was noted. Similarly corresponding mass of water filled bottle was found as (W_3) for the water being tested.

$$\text{Density of the tested water } (\rho l) = W_3 - W_2/W_2 - W_1 \text{ gm cc}^{-1}$$

W_1 = mass of empty specific gravity bottle along with stopper, gm, W_2 = mass of specific gravity bottle with distilled water, gm, W_3 = mass of specific gravity bottle with the tested water, gm.

Surface tension

The surface tension of spray liquids has great influ-

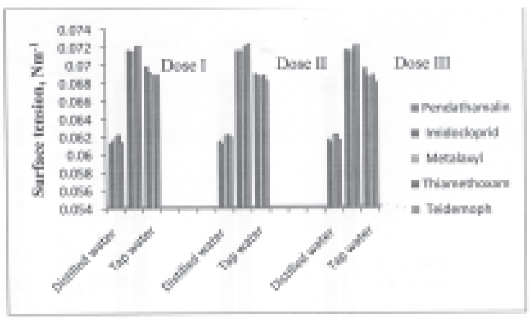

Fig. 2. Effect of doses, water quality and chemical type on Suaface tension of spray liquid.

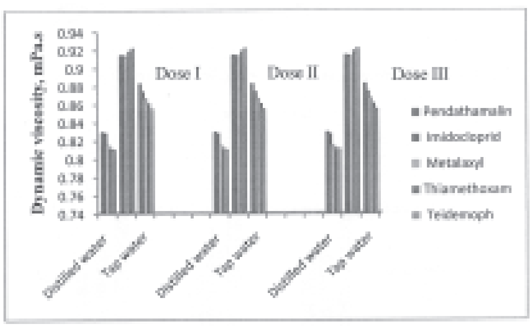

Fig. 3. Effect of doses, water quality and chemical type on dynamic viscosity of spray liquid.

Table 3. Anova table for effect on surface tension with changes on doses, water quality and type of chemicals. a. R Squared = .980 (Adjusted *R* Squared = .970).

Source	Type III sum of squares	Degree of freedom	Mean square	*F*	Sig.
Corrected model	0.002[a]	44	5.468E-5	97.845	0.000
Intercept	0.613	1	0.613	1096125.312	0.000
DOSE	3.290E-7	2	1.645E-7	0.294	0.746
Water quality (WQ)	0.002	2	0.001	2135.654	0.000
Chemical (C)	2.980E-6	4	7.449E-7	1.333	0.264
DOSE * WQ	1.473E-6	4	3.682E-7	0.659	0.622
DOSE * C	7.636E-7	8	9.544E-8	0.171	0.994
WQ * C	1.190E-5	8	1.487E-6	2.661	0.011
DOSE * WQ * C	1.484E-6	16	9.272E-8	0.166	1.000
Error	5.030E-5	90	5.589E-7		
Total	0.615	135			
Corrected total	0.002	134			

ence on the formation of droplets, the capacity for wetting the target surface and the maximum possible electrical charge that the droplet can accumulate. The minimum energy required for atomization is equal to the surface tension multiplied by the surface area of the droplet. The surface tension also limits the electrostatic charge a drop can have without rupture. Hence it was also used as a property based on which liquid was categorized in our experiment. The surface tension of the spray liquids were found by drop weight method -forming cylindrical drops at the tip of a burette nozzle. This procedure provided for replicating the experiment thrice in single setting. Using a screw gauge, the diameter of the tip of the burette nozzle was measured at different points along the tip and the average radius of the tip (r) was calculated by following relationship

$$\sigma = Mg/3.8\ r \quad Nm^{-1}$$

Where, g = acceleration due to gravity, 9.8 ms $^{-1}$, r = radius of the tip of the burette, $1.635 * 10^{-3}$, M = average mass of the single drop of the liquid, kg.

Dynamic viscosity

The dynamic viscosity of spray liquids has direct ef-

Table 4. Anova table for effect on dynamic viscosity with changes on doses, water quality and type of chemicals. a. *R* Squared = .816 (Adjusted *R* Squared = .726).

Source	Type III sum of squares	Degree of freedom	Mean square	*F* value	Significance
Corrected model	0.226[a]	44	0.005	9.054	0.000
Intercept	101.485	1	101.485	178803.602	0.000
DOSE	2.055E-5	2	1.027E-5	0.018	0.982
Water quality (WQ)	0.217	2	0.109	191.338	0.000
Chemical (C)	0.004	4	0.001	1.790	0.138
DOSE * WQ	1.772E-5	4	4.430E-6	0.008	1.000
DOSE * C	5.330E-5	8	6.663E-6	0.012	1.000
WQ * C	0.005	8	0.001	1.030	0.420
DOSE * WQ * C	7.221E-5	16	4.513E-6	0.008	1.000
Error	0.051	90	0.001		
Total	101.762	135			
Corrected total	0.277	134			

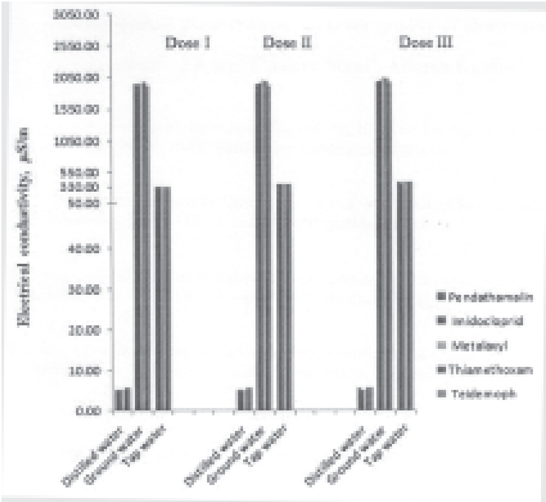

Fig. 4. Effect of doses, water quality and chemical type on electrical conductivity spray liquid.

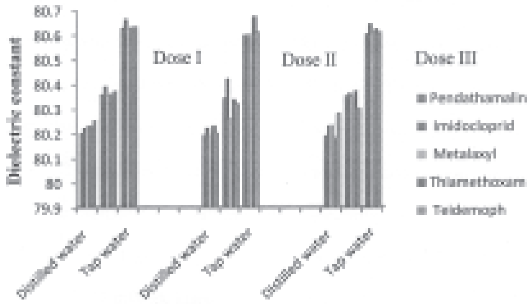

Fig. 5. Effect of doses, water quality and chemical type on dielectric constant of spray liquid.

fect on the flow of the spray liquids through the nozzle and thereby the formation of droplets and deposition onto the target are influenced. Increased dynamic viscosity delays atomization and increases the size of droplets. Hence this property was determined towards characterizing the spray liquid used for our experiment. For present study the dynamic viscosity of test spray liquid was measured directly by MCR Rheometer series from Anton Paar at 25°C at recommended formulations.

Assessment of electrical properties of the spray liquids

Electrical conductivity and dielectric constant are the two main electrical properties, which greatly affect the chargeability of the spray liquid. Charge-transfer capability by conduction from the grounded spray fluid through the jet depends upon its electrical properties.

Electrical conductivity

Apart from the applied voltage, electrical conductivity of the liquid decides the charge attained by spray droplet. The level of droplet charge imparted by the electrostatic induction process depend heavily upon the relative time rate of charge transfer to the droplet-formation zone as compared with the time required for droplet formation. The charge transfer time constant (τ) or charge relation is a function of the electrical conductivity. Generally spray liquids having low (<$10^{\wedge -4}$ m seimen m^{-1}) electrical conductivity (EC) meter towards assessing whether the liquids are suitable for induction charging and allow to characterize the assessing whether the liquids are suitable for induction charging and allow to characterize the liquids under consideration. For present study the spray solutions were prepared with recommended doses and EC was calculated by directly inserting knob of hand held EC meter in spray liquid. Reading was obtained in terms of dsm^{-1} in digital display.

Dielectric constant

Dielectric constant of spray liquid is a function of charge transfer time constant (r) and is the main factor with regard to charge transfer. Dielectric constant of spray liquids was measured by using a parallel plate apparatus similar to capacitor. It was constructed as to have two parallel aluminium plates of equal area facing each other with a particular gap in between, for accommodating the dielectric. The basic expression of parallel plate capacitance was used for development of this apparatus. For a capacitor.

Table 5. Anova table for effect on electrical conductivity with changes on doses, water quality 0 and type of chemicals. a. *R* Squared = 1.000 (Adjusted *R* Squared = .999).

Source	Type III sum of squares	Degree of freedom	Mean square	*F*	Sig.
Corrected Model	1.665E8	44	3783099.482	5287.216	0.000
Intercept	1.211E8	1	1.211E8	169251.589	0.000
DOSE	21.870	2	10.935	.015	0.985
Water Quality (WQ)	1.664E8	2	83214330.302	116299.377	0.000
Chemical (C)	8702.797	4	2175.699	3.041	0.021
DOSE * WQ	67.084	4	16.771	0.023	0.999
DOSE * C	824.856	8	103.107	0.144	0.997
WQ * C	16498.114	8	2062.264	2.882	0.007
DOSE * WQ * C	1601.896	16	100.119	0.140	1.000
Error	64396.646	90	715.518		
Total	2.876E8	135			
Corrected Total	1.665E8	134			

$$C = K\varepsilon_o A/D$$

Where, C= capacitance of the capacitor, F, A = cross sectional area of parallel plate capacitor, m^2, D = distance between two parallel plate capacitor, m, ε_0 = permittivity of air, ($9.854*10^{-12}$ C^2 N^{-2} m^{-2}).

Based on these designed values a parallel plate apparatus was prepared. The spray liquid in was filled up to the brim in the apparatus and dielectric constant (K) was determined by substituting the measured capacitance in the equation.

Results and Discussion

The various electromechanical properties like Density, Surface tension, Dynamic viscosity, Electrical Conductivity and Dielectric constant for selected chemicals were determined. The observed values were used to determine the range of the design values of different components and capacity of electrostatic sprayer in terms of charge mass ratio, size and voltage of electrode, orientation of electrode and electrode position. The statistical analysis of data was performed to assess the significance of the variables viz., water quality (WQ), Chemical used (Ch) and doses (D) on electromechanical properties of spray liquid.

Density

The ANOVA (Table 2) revealed that there was significant difference among the trea\tments. The water quality (WQ) and Chemical type (Ch) was found to significantly effect the density at 5% level of significance, however density was found to remain almost same for every water quality and chemical type at different dosage level (Fig. 1). The density value was found to change with quality of water. Ground water was found to have maximum density with all the formulations. Teidemoph with ground water showed maximum density of 1.005684 gm cc^{-1} while Pendathamalin was found to have minimum density of 1.0034956 gm cc^{-1}. Since the value of calculated density for formulations with ground water and tap water was close to that of with pure water. So it was recommended to use available tap water and/or ground water for preapartion of formulation for spraying pesticides.

Surface tension

The density of spray liquid remains same irrespective of the type of chemical formulation with recommended doses. The minimum energy required for atomization is equal to the surface tension multiplied by the surface area of the droplet. The surface tension also limits the electrostatic charge a drop can have without rupture. Hence it was also used as a property based on which liqued was categorized in our experiment. The results of ANOVA (Table 3) indicated that there was significant difference among the treatments. The individual effect of dose (D) doesnot have any sig-

Table 6. Anova table for effect on dielectric constant with changes on doses, water quality and type of chemicals. a. *R* Squared = .816 (Adjusted *R* Squared = .726).

Source	Type III sum of squares	Degree of freedom	Mean square	*F* value	Significance
Corrected Model	0.226[a]	44	0.005	9.054	0.000
Intercept	101.485	1	101.485	178803.602	0.000
DOSE	2.055E-5	2	1.027E-5	0.018	0.982
Water Quality (WQ)	0.217	2	0.109	191.338	0.000
Chemical (C)	0.004	4	0.001	1.790	0.138
DOSE * WQ	1.772E-5	4	4.430E-6	0.008	1.000
DOSE * C	5.330E-5	8	6.663E-6	0.012	1.000
WQ * C	0.005	8	0.001	1.030	0.420
DOSE * WQ * C	7.221E-5	16	4.513E-6	0.008	1.000
Error	0.051	90	0.001		
Total	101.762	135			
Corrected Total	.277	134			

nificant effect at 5% leval of significance. Whereas the water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance. Figure 2 graph clearly shows the effect of water quality on surface tension. It is evident from the graph that ground water requires maximum electrostatic force to atomize the spray liquid since surface tension was found to be maximum for formulations prepared in ground water. Teidemoph with ground water showed maximum surface tension of 0.07201 Nm^{-1}. The results clearly supports the literature that CMR value for ground water formulations will be maximum since electrostatic charge required for breaking per kg of spray liquid will be highest in case of ground water.

Dynamic viscosity

The dynamic viscosity of spray liquids has direct effect on the flow of the spray liquids through the nozzle, and thereby the formation of droplets and deposition onto the target are influenced. Increased dynamic viscosity delays atomization and increases the size of droplets. Hence this property was determined towards characterizing the spray liquid used for our experiment. The results of ANOVA (Table 4) indicated that there was significant difference among the treatments. The individual effect of dose (D) doesnot have any significant effect at 5% level of significance. Whereas the water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance. The results obtained from antaan par rheometer was plotted in graphs (Fig. 3). The graph clearly showed similar results with density and surface tension. But in case of distilled water and tap water the value of dynamic viscocity was minimum with teidemoph compared to ground water where it showed maximum value of 0.92103 mPa.s.

Electrical pproperties of the spray liquids

Electrical conductivity and dielectric constant are the two main electrical properties, which greatly affect the chargeability of the spray liquid. Charge-transfer capability by conduction from the grounded spray fluid through the jet depends upon its electrical properties. The charge transfer time constant (τ) or charge relation is a function of the electrical conductivity. Generally spray liquids having low ($<10^{\wedge-4}$ mseime-nm^{-1}). The results of ANOVA (Table 5) indicated that there was significant difference among the treatments. The individual effect of dose (D) doesnot have any significant effect at 5% level of significance. Whereas the water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance. The results of EC from the above Figure 4 shows lot of variation with respect to water quality. It clearly depicts that the

Table 7. Recommended values of electromechanical properties required for electrostatic charging of spray droplets.

Sl. No.	Electromechanical properties	Recommended values for electrostatic spraying
1.	Density	1.0025881-1.0056984 gm cc^{-1}
2.	Surface Tension	0.06821-0.07201 Nm^{-1}
3.	Dynamic Viscosity	0.87155-0.92103 mPa.s
4.	Electrical Conductivity	563 - 1950 µs/cm
5.	Dielectric Constant	80.2 - 80.7

presence of soluble minerals in ground and tap water resulted in higher value of EC compared to distilled water. Since the soluble salt concentration was higher in ground and tap water for all dosages of chemical, therefore EC was higher in case of ground and tap water. In this case the maximum value of EC (563 µs/cm) was obtained in case thiamethoxam with tap water.

Dielectric constant

Dielectric constant of spray liquid is a function of charge transfer time constant (τ) and is the main factor with regard to charge transfer. Dielectric constant of spray liquids was measured by using a parallel plate apparatus similar to capacitor. It was constructed as to have two parallel aluminium plates of equal area facing each other with a particular gap in between, for accommodating the dielectric. The results of ANOVA (Table 6) indicated that these was significant difference among the treatments. The individual effect of dose (D) doesnot have any significant effect at 5% level of significance. Whereas the water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance Figure 5. The graph shows the effect of water quality with different chemical formulation on dielectric constant. In case of dielectric constant the value was maximum in case of tap water. Since the tap water selected for study may contain mineral and ions which have property of holding charge for maximum duration. Therefore dielectric constant for tap water was found to be maximum. All the above results clearly showed that the chemical formulation with varying doses dose not have any significant effect on electromechanical properties of spray liquid. It may be due to the fact the doses used per liter water was minimal to effect the required properties. Whereas the water quality and chemical use showed significant difference on electromechanical properties of spray liquid.

Conclusion

Electromechanical properties of spray liquid effect the droplet formation, terminal velocity, charge transfer capacity and deposition efficiency required for design of electrostatic sprayer. It was observed the individual effect of dose (D) doesnot have any significant effect at 5% level of significance. The water quality (WQ) and Chemical (Ch) has significant effect individually as well as in treatment combination at 5% level of significance. Ground water requires maximum electrostatic force to atomize the spray liquid since surface tension was found to be maximum for formulations prepared in ground water . The recommended values of electromechanical properties (Table 7) is required to get desired CMR for charging atomized spray particle. Therefore tap water is recommended to determine the efficiency of electrostatic sprayer.

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