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Electrostatic hand pressure knapsack spray system with enhanced performance for small scale farms

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ABSTRACT

Electrostatic force fields have been employed and enhanced in the design of an electrostatic knapsack spray system for increasing the deposition efficiency and reducing the drift of pesticides. The designed induction charge based electrostatic sprayer offers optimum electrode position and electrical conductivity of liquid. The experiments were conducted in ambient conditions for liquid feed rate 340 ml/min at hand pressure of 30 psi. The charge-to-mass ratio was found to be 0.419 mC/kg at 3.25 kV by a spray liquid of conductivity 10.25 mS/cm. There has been 2–3 fold increase of chemical deposition with better uniformity on the target (potted plant).

1. Introduction

The application of pesticide is one of the most frequently used methods to protect crops and trees against diseases and insects in agriculture [1,2]. In the modern agriculture, the usage of pesticides is still increasing [3], moreover the 90% of these pesticides are being applied in the form of liquid spray and mostly by using the pressure swirl nozzles or air assisted nozzles [4]. Conventional spray techniques have been suffering from over dosage, off-target spray, and non-uniform deposition of pesticide [5], leads to many problems such as chemical waste (economic) and environmental pollution from spray drift [6] and makes them unable to protect the crops efficiently because of the absence of spray on hidden surfaces of the plant [2,7,8]. The current trend toward prevention of chemical waste and environmental pollution is the application of an electrostatic spray technique [9–13].

Although, this technique is already commercialized and being used in some countries [14], there are many parameters involved in the induction charge based electrostatic-spray system for more refinement. As the investigations carried out thus far have demonstrated the intricacies of the electrostatic-spray phenomena, there is a need to characterize and optimize every single parameter so that the technique will be enhanced. Earlier electrostatic spray systems were motorized and mounted on tractors [15], helicopters, and other vehicles. However, because of the complexity and bulky, they caused the economic burden to the small scale farmers. The goal of pesticide spray application is not only the effective deposition onto the target, but also economical [16].

This article details a hand pressure knapsack sprayer with pressure swirl nozzle which successfully adapted an induction charge based electrostatic sprayer. It also discusses the optimization of parameters like electrode position, applied pressure, electrical conductivity of spray liquid, and applied voltage to enhance the efficiency and efficacy of the system that can be attractive for the small and medium scale farmers.

2. Experimental setup

The electrostatic hand pressure swirl nozzle designed for the experiment is shown in Fig. 1. A swirl disc having two swirl holes of diameter 1.0 mm and an orifice disc with hole of diameter 0.8 mm have been used. A ring electrode made up of pure copper was used for the process of electrification on the basis of electrostatic induction by supplying positive high voltage, where as a stainless steel electrode placed behind swirl disc was facilitating the ground. The position of ring electrode from the orifice disc is being varied

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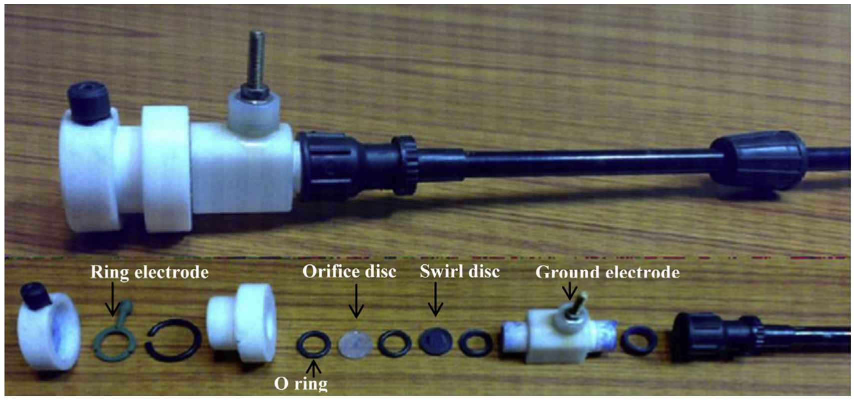

Fig. 1. Electrostatic pressure swirl nozzle and internal parts.

ranging from 1.0 mm to 7.0 mm as well as its dimensions have chosen for close contact with liquid sheet. Teflon coating of uniform thickness 200 μm was used to isolate the ring electrode to prevent the wetting effect. A programmable 10 W high voltage module (EMCO high voltage corporation, Model No: F101) ranging from 0 to 10 kV was used for the experiment(s).

A manual hand pressure knapsack spray pump having the pressure range from 0 to 35 psi was used to pressurize the liquid to be sprayed. A tap water with physical and electrical properties as given in Table 1 was used as spray liquid for testing purpose. To optimize the liquid conductivity, the same liquid was used with different electrical conductivities acquired by mixing Sodium Chloride (NaCl). A potted coleus plant (Botanical Name: *Solenostemon scutellarioides* 'Versa Lime') was used as a target to test the wraparound effect and spray uniformity within laboratory at ambient conditions $T = 23 \pm 2$ °C, RH $= 53 \pm 5\%$.

The experimental set-up shown in Fig. 2 consists of a hand pressure knapsack spray pump, precision pressure gauge, swirl nozzle, 10 W miniature DC to HV DC converter, DC power supply, High voltage probe (TESTEC High Voltage Probe TT-HVP 40) with digital multimeter (*ISO-TECH/DM67*), artificial targets, and a potted plant.

As shown in Fig. 2, the liquid (tap water) was sprayed on to different artificial targets such as glass beaker, plastic ball, and aluminum plate etc. Experimentally, the charge-to-mass ratio (CMR) was calculated from the ratio of spray cloud current i_s to mass flow rate Q_m. The CMR describes the relative ability for the electrical forces to overcome the forces due to gravity and kinetic energy imparted to the droplets [17,18].

$$\text{Charge} - \text{to} - \text{mass ratio} = \frac{i_s}{Q_m}$$

In this study, the former definition of existing electrostatic method for measuring CMR has been used, i.e. Faraday cage or current measuring electrode. A specially designed Faraday cage (Fabricated at CSIR–CSIO, Chandigarh) was used along with programmable electrometer (Model No. 6514, Keithley Make, USA) in current mode to measure the spray current as shown in Fig. 3. The charged liquid spray was collected at a specific time and weighed. Then the spray current was divided by the mass flow rate to determine the charge to mass ratio.

Table 1
Properties of normal tap water used for the experiment(s).

Conductivity	($\sigma = 0.45$ mS/cm)
Density	($\rho_l = 998$ kg/m^3)
Viscosity	($\mu \approx 1.002 \times 10^{-3}$ Pa s or kg/m s)
Surface tension	($\gamma \approx 0.072$ N/m)
Permittivity	($\varepsilon \approx 708.88 \times 10^{-12}$ C^2/N m^2)
Dielectric constant	($\varepsilon_r \approx 80$)
Resistivity	($\rho_e = 22.2$ Ω m)

3. Results and discussion

The liquid flow rate Q_v was measured with respect to applied pressure as given in below Table 2. Number of experiments were carried out by varying the parameters of voltage, pressure, electrode position, and liquid conductivity on different targets and corresponding results were noted down. Each experiment was repeated under the same conditions for better accuracy. The results have been used to optimize the most important parameters mentioned above.

3.1. Effect of applied pressure

At a constant applied voltage 3.0 kV, the spray current was measured with respect to applied pressure at three different electrode positions. Normal tap water of electrical conductivity 0.45 mS/cm was used as spray liquid. The change in applied pressure modulates the breakup length and liquid flow rate which in turn decides the electrode position and maximum spray current and hence CMR.

Fig. 4 illustrates the effect of applied pressure on spray current. It is evident from Fig. 4, that even the three plots are shifted from each other; they are having similar response to the pressure. This may be attributed to four reasons for the spray current response, viz., (i) High pressure which causes heavy flow thus more current but no effect on CMR [19], (ii) High pressure also results in small droplets thus more surface area and more spray current [20], (iii) The change in the breakup length causes rapid change of chargeability (from positive to negative) in a fixed electrode nozzle [21,22], and (vi) Pressure reduces the droplet formation time and hence the charge acquired by them for low conductive solutions.

For different electrode positions, there are different optimum values of pressure. At different electrode positions the CMR with respect to the applied pressure is as shown in Fig. 5. As the electrode moves from 5.0 mm to 4.5 mm distance the optimum pressure also shifted from 25 psi to 30 psi which causes finer spray, and hence offered an improved CMR. But in case of electrode distance 4.0 mm the optimum pressure is out of range due to the limitations of hand pressure. From Fig. 5 it is clear that 30 psi is the most suitable value for the designed spray system.