Computers and Electronics in Agriculture 135 (2017) 280–288

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

An advance air-induced air-assisted electrostatic nozzle with enhanced performance

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ARTICLE INFO

Article history:
Received 1 December 2016
Received in revised form 9 February 2017
Accepted 11 February 2017
Available online 24 February 2017

Keywords:
Aerodynamics
Electrodynamics
Hydrodynamics
Volume Median Diameter (VMD)
Number Median Diameter (NMD)

ABSTRACT

There is a pressing need of new chemical application sprayer for small scale farms in Indian agricultural pesticides spraying. A new air-assisted electrostatic nozzle has been designed and developed for small scale farms with a specific focus on Indian agricultural and rural developing economies. An air-assisted electrostatic nozzle is a combination of an air-assisted nozzle and induction based electrostatic charging system. Spray droplets are electrified to more than 10 mC/kg charge-to-mass ratio by charging voltage less than 2.5 kV at liquid flow of 150 ml/min and electric power consumption less than 75 mW. Higher charge-to-mass ratio ensured the high range spraying distance to overcome the charge neutralization by recombination of naturally occurring ions present in the environment and charged liquid droplets. The results of applied induction electrification process were characterized by a charge-to-mass ratio and the results are in good agreement with the theoretical considerations. There has been 2–3 fold increase of liquid deposition with better uniformity on the obscured as well as front target. This nozzle is light weight, highly efficient, reduces pesticide use and human health risks, and eco-friendly.

1. Introduction

In the process of sustainable agricultural development, pesticides have become as a plant protection agent from many dreadful diseases and insects, for boosting food production to fulfill the basic human needs (Pimentel and Levitan, 1986; Al-Saleh, 1993; Abhilash and Singh, 2009). The pedestal-mounted sprayers, the high pressure spray guns, the hand pressure swirl nozzles and the consecutive high volume spraying are still used in Indian agriculture spraying (Kacprzyk and Lewandowski, 2011; Mamidi et al., 2012; Yang et al., 2012; Pascuzzi and Cerruto, 2015). The conventional and outdated spraying techniques and equipment results in many problems such as high volume but low efficiency of the pesticides deposited on the targets, most of the pesticide lost in the surroundings due to off-target spray drift, causing contamination to soil, water and eco-system which results in human health risks, and serious environmental pollution (Ru et al., 2008; Xiongkui et al., 2011; Ezhilarasi et al., 2013; Guthman and Brown, 2015).

The electrostatic force field application to agricultural spraying, one of the most promising methods to apply the protective liquid based sprays onto the biological surfaces of living crops and orchards, has revolutionized the agricultural pesticide spraying techniques by making advances and developments via off-target pest control to increase the deposition efficiency and pesticides bio-efficacy (Law, 1983; Ru et al., 2011; Mamidi et al., 2013; Patel et al., 2015a, 2015b, 2016). In agro chemical, bio-efficacy is a measure of the biological efficacy of an active ingredient of agrochemical such as insecticide. Bio-efficacy of an insecticide is determined by the minimum dose required for maximum control of the disease. It has been used in many other industrial applications such as thin film deposition, edible food coatings, painting, printing, medical devices and pharmaceuticals (Laryea and No, 2003; Yu et al., 2008; Baldwin et al., 2011; Lyons et al., 2011; Ghanshyam et al., 2013; Krupa et al., 2013; Pérez-Masiá et al., 2014; Manoj Kumar and Chirravoori, 2015; Patel et al., 2015a, 2015b). Electrostatic spraying achieves more complete coverage of difficult targets than uncharged spraying in addition to minimizing wastage and environmental impact from over-dose and off-target spray drift. Earlier electrostatic spray systems developed and commercialized were motorized and mounted on tractors, helicopters, and other

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http://dx.doi.org/10.1016/j.compag.2017.02.010
0168-1699/

vehicles, which are not suitable and economical to Indian farmers because of geographical conditions and economic constraints (Yu et al., 2007). According to Agricultural Census Division, in India, the farming is carried out in small scale; and the farm lands are divided in small pieces of land, it may because of government policy of allocation of farms or geographical and agro-climatic conditions (Patel et al., 2015a, 2015b). It will not only true in case of Indian farming but also for any small scale farming of any other geographies and economies. Most of the Indian farmers are way behind with available electrostatic sprayers because of financial reasons and availability. They need robust pesticides application equipment so that it can be used with minimum labors or almost without any exceptional expertise. However, because of the complexity and heaviness, they cause the economic burden to the small scale farmers. The goal of pesticide spray application is not only the effective deposition onto the target, but it should also be economical and affordable (Laryea and No, 2004; Chigier, 2006; Sasaki et al., 2013).

Despite of available literature, it is obvious that very little research work has been carried out on optimization of design and performance parameters of air-assisted electrostatic nozzle such as electrode position, electrode material for spray charging, liquid flow rate, trade-off between air pressure and liquid flow rate, range of resistivity of liquid to be sprayed, high voltage generation, power consumption (Balachandran and Bailey, 1981; Kuroda et al., 2003; Patel et al., 2016b, 2016c, 2016d). In the earlier research work, we have worked on plausibility of variable coverage high range spraying, hand pressure Knapsack sprayer, characterization of electrode materials for spray charging and optimization of electrode position, high voltage generation (Patel et al., 2016c, 2016d). In this paper, the theoretical and engineering aspects of the design and development of indigenously and low cost air-induced air-assisted electrostatic nozzle with enhanced performance have been presented. This paper describes the design aspects and performance parameters of an electrostatic nozzle, which were not yet reported. It also elucidates the high voltage generated from a rechargeable battery raised to several kilovolts in housed with nozzle itself i.e. DC to DC converter which is application specific and indigenously developed for the designed nozzle system. The designed nozzle uses a new electrode material for charging of liquid sprays i.e. nickel, which is assumed to be an inert material at standard pressure and temperature, to avoid the corrosion and oxidation of the electrode embedded in the nozzle (Patel et al., 2012, 2016a). The experimental results show that the performance of an air-assisted electrostatic nozzle has been enhanced significantly in terms of increase in charge-to-mass ratio and hence deposition efficiency, mass transfer and bio-efficacy.

2. Material and methods

Air-assisted electrostatic nozzle design parameters include hydrodynamics of liquid flow and atomization of liquid, charging of liquid sprays, charging electrode material, electrodynamics, transportation of charged liquid droplets, aerodynamics, and deposition of charged droplets onto the target (Chang et al., 1995; Biris et al., 2004). For the charging of the liquid sprays a high voltage is required, which consists of a rechargeable battery and a DC to DC converter, the voltage of rechargeable battery raised to several kilovolts, connected to charging electrode. The charging of conductive liquid is based on induction principle which is most reliable and field proven method for imparting the charge efficiently. In air-assisted electrostatic nozzle design, the parameters to be optimized are: charge-to-mass ratio, a depended variable with the variation of independent variables such as applied voltage, resistivity of liquid, applied air pressure and air flow, liquid flow rate and target distance (Lenard, 1892; Khuri and Mukhopadhyay, 2010; Patel et al., 2015c). The variation of charge-to-mass ratio with the change in liquid resistivity is an important parameter in the nozzle design, since it is very necessary to cover all the liquid based insecticides with optimum performance of the system. Though, this paper presents only the engineering design aspects however, a set of field observations are carried out to discuss the deposition efficiency, droplet size, uniformity of coverage and swath width (Mostafaie Maynagh et al., 2009; Maski and Durairaj, 2010).

A twin fluid, internal mixing, air-induced, concentric, air-assisted electrostatic nozzle with annular ring electrode of appropriate dimensions made of nickel has been designed and developed as shown in schematic diagram of Fig. 1. A cylindrical nozzle tip of length 14 mm is taken to pass the liquid in the form of narrow jet. Here the orifice/tip hole of diameter 1.4 mm is extended up to the other end of the cylindrical part to connect with input pipe through the coupler. The cone angle of spraying of the designed nozzle is approximately 25°. This design is in such a way that to ensure proper co-axial alignment between annular ring electrode and the nozzle. The designed spraying system, especially for agricultural crops and orchards applications, is technologically advanced. We have worked on electrode material for spray charging and optimization of spray charging parameters (Patel et al., 2013).

The charge induced on the jet is proportional to the surface area exposed to electric field and the magnitude of the normal component E_n of the field. The amount of induced charge q_t may be expressed as $q_t = \varepsilon_0 \varepsilon_r \int E_n dA$, where ε_0 and ε_r are vacuum and relative permittivity constants respectively and dA is the area element exposed towards liquid surface. For the given construction of nozzle body which dictates the jet break-up process, this effect must be achieved by proper selection of the geometry of the charging electrode arrangement. For developed nozzle, assume that the average value of height (h) of liquid tank is approximately 0.5 m. Therefore, the velocity of the liquid flow approximately is 3.13 m/s. The pressure head of the liquid having the height of 0.5 m is 0.05 bars i.e. 5000 Nm^{-2}. It means that, even if you apply some pressure to the liquid to overcome the liquid head problem, it should not exceed 0.05 bars otherwise the flow rate might be changed. It is found that for the better/finer spray, the liquid to air ratio supposed to be appropriate, and most commonly used liquid flow for agriculture spray nozzle is 100–200 ml/min.

The method used here for the droplet charging is induction electrification process, reducing the shock and hazardous to operate the nozzle system (Edward Law, 2001). In electrostatic induction charging, direct charge-transfer to droplet formation zone of a liquid jet results from electrostatic induction of electrons onto the continuous jet and in order to maintain it at ground potential, the presence of a closely positioned electrode of positive polarity is required. In electrostatic spraying the electrode material is playing a key role in induction spray charging. In our experimental and field trials, nickel has been used as an electrode material for spray charging.

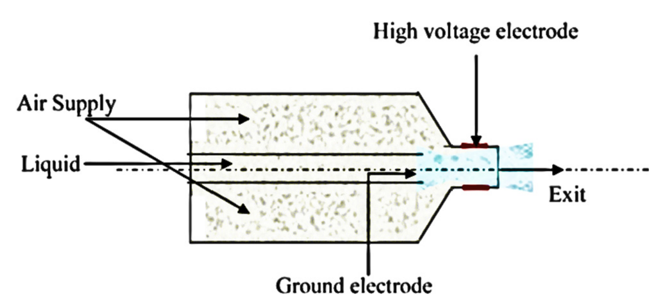

Fig. 1. Schematic diagram of air-induced air-assisted electrostatic nozzle.