Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

The effect of air velocity and proximity on the charging of sprays from conventional hydraulic nozzles

S. Gan-Mor*, B. Ronen, K. Ohaliav

Institute of Agricultural Engineering, ARO, Volcani Center, POB 6, Bet Dagan 50250, Israel

ARTICLE INFO

Article history:
Received 27 August 2012
Received in revised form
6 March 2014
Accepted 11 March 2014
Published online 1 April 2014

Keywords:
Sprayer
Electrostatic
Charge
Air velocity
Insulation
Hydraulic nozzle

Conventional nozzles where hydraulic pressure is used to form the spray, are widely used in agricultural spraying. In many cases they rely on air assistance to efficiently convey the spray droplets to the target. The addition of a further depositing force based on electrostatic charging can significantly improve deposition, particularly on the shaded or hard-to-reach surfaces. The positioning of induction-charging electrodes close to nozzle outlets was investigated. In the laboratory the charging of a conventional flat-fan hydraulic nozzle was investigated. Optimal spacings were found when a high ambient air velocity was used to prevent charged droplets depositing on the electrodes and their insulated mountings. The moving air also dried them continuously, thereby prevented leakage. The results show that a current of 13.9 μA per nozzle was attainable for a spray pressure of 400 kPa with a liquid flow rate of 0.45 l min^{-1} and droplet spectrum with a 115 μm volume medium diameter (VMD). This is equivalent to a charge-to-mass ratio of 1.85 mC kg^{-1}. These high currents and high charging levels were achieved by using air velocities > 10 m s^{-1}. Laboratory tests showed that the spacing between nozzles could be too small, reducing the level of charge per nozzle. A field sprayer was designed with nozzles using a higher flow rate than those investigated in the laboratory. Field tests of the prototype sprayer in a commercial vineyard showed that electrostatic charging improved the deposition of droplets containing a fluorescent tracer by 200 and 500% on the leaf undersides and the rear of grape clusters, respectively.

1. Introduction

Uniform deposition and the application of sufficient amounts of active material are important when applying pesticides (Gamliel et al., 2004; Gamliel, Riven, Steiner, & Beniches, 2010; Gan-Mor, Grinstein, Beres, Riven, & Zur, 1996). The importance of obtaining good leaf coverage has increased with the increasingly severe regulations relating to pesticide residues, and as demands for toxic-material-free products intensify. The most commonly used technique for generating droplets in agricultural spraying involves atomising liquid into fine

* Corresponding author.
E-mail address: ganmor@volcani.agri.gov.il (S. Gan-Mor).
http://dx.doi.org/10.1016/j.biosystemseng.2014.03.004

Nomenclature

VMD	volume medium diameter
U	electrode potential
v	air jet velocity
I	electric current
L	gap between the electrodes
h	electrodes to nozzle distance

spray by means of hydraulic pressure. Hydraulic pressure forces the liquid thorough a metal, ceramic or plastic orifice, thereby creating a liquid sheet which breaks into fine droplets. The introduction of air streams to assist the transport of spray towards the target can improve deposition uniformity (Gamliel et al., 2004). The process can be further improved by the use of electrostatic forces: droplets can be charged and so they approach the target as a charged cloud (Law, 2001).

Electrostatic charging is very common in industrial painting, where the advantage of spray charging is enhanced when high charge-to-mass ratios are achieved. In agricultural spraying, when appropriate charging levels are applied, the coverage can be uniform and significant amounts of material can be deposited, especially on "hard-to-reach" surfaces such as the undersides of leaves on the lower parts of row crops (Law, 2001). If the level of charge is low then there can be no improvement in coverage. It is therefore important to ensure that an adequate level of charge is obtained so that improvements in deposition can be achieved. Agricultural sprayers that provide a high level of electrostatic charging, in addition to air assistance, have achieved an average of 150% improvement in spray deposit density with significantly improved coverage on hard-to-reach surfaces. Sprayers using these methods have been offered commercially by ESS Inc. (Watkinsville, GA, USA) since 1988 (Law, 1978; Law & Schrem, 2005). The ESS nozzles use high-air pressure to break the liquid into droplets; they provide finer spay with a volume median diameter < 50 μm.

In laboratory tests Hensley, Feng, and Bryan (2008) achieved a maximum charge-to-mass ratio of approximately 0.5 mC kg^{-1} with a VV-SS 8005-1/4 hydraulic nozzle (Spraying Systems Co., Wheaton, IL, USA); the pressure was 140 kPa and the average droplet diameter was 500 μm. Higher pressures and finer sprays are generally recommended for achieving uniform deposition in agriculture (Gamliel et al., 2010). In the tests by Hensley et al. (2008) the large diameter and the absence of air assistance clearly impaired the achievement of good coverage. However, the charge-to-mass ratio achieved by Hensley et al. (2008) was relatively high and it can serve as a reference level for improvements.

Inculet and Castle (2001), without the use of air assistance, achieved approximately half the charge-to-mass ratio achieved by Hensley et al. (2008). Laryea and No (2003) achieved up to 130% improvement in deposition by using special nozzles at a hydraulic pressure of 2400 kPa, and achieved a charge-to-mass ratio of 0.27 mC kg^{-1}; their tests were conducted in an orchard and they used a charging potential of 4.0 kV. However, these nozzles were not suitable for continuous use at this pressure; the nozzles worked properly for reasonable periods when used at 2000 kPa, when they produced droplets of 116 μm volume medium diameter (VMD), but it yielded a lower deposition improvement. They conducted their tests with no air assistance and the deposition improvements could be related to the relatively short outlet-to-target distances; they were similar to those used for industrial painting.

High charge-to-mass ratios have been achieved by using induction for the charging of the spray droplets (Law, 1978, 2001; Marchant, 1985) and by using triboelectric or corona charging for solid particles (Gan-Mor, Bechar, Ronen, Eisikowitch, & Vaknin, 2003; Kleber & Makin, 1998; Mayr & Barringer, 2006). Induction charging provides high charge-to-mass ratios when the induction electrodes were placed in front of the liquid outlet; and, in order to avoid wetting of the electrodes, slightly to the side of the spray jet or sheet (Hensley et al., 2008; Inculet & Castle, 2001; Laryea & No, 2003). The short distance between the electrode and the jet led to charging instability, because some of the charged droplets deposited on the electrode caused charge transfer to the electrode along with occasional sparks (Hensley et al., 2008). This caused electric current, electrical load, potential drop and unstable charging. Small-diameter high-air-pressure nozzles were used by Law (1978) and others (Giles & Law, 1985; Law & Cooper, 1987) to prevent the charged droplets from hitting the electrodes and thereby keeping the electrodes dry. The air pressure was around 200 kPa and it also served to break the liquid into fine spray, as noted above. All the above studies, as well as those by Marchant and Green (1982) and Marchant (1985), reported on methods of confronting insulation issues while using hydraulic spray nozzles or spinning-disc atomisers. Good insulation of the electrodes, particularly where airflow prevents charged droplets from hitting electrodes and their mountings, can help when striving for a stable electrode potential and high and stable charge-to-mass ratios.

Laryea and No (2003) obtained significant deposition improvement when they used a charge-to-mass ration of 0.27 mC kg^{-1} and short outlet-to-target distances. Law (2001) maintained that charge-to-mass ratios less than 1.5 mC kg^{-1} provided only marginal improvements in deposition for the large outlet-to-target distances that are typical to aerial spraying. Large outlet-to-target distances cause spray clouds moving through the air to be diluted by the interaction with the surrounding air. This leads to a reduction in the space charge and electric field intensity close to the target. Thus, good conditions for electrostatic spraying are when the outlet-to-target distances is minimal and the charge-to-mass ratio is more than 1.0 mC kg^{-1} for intermediate distances. The forces dominating the trajectories of charged particles and their contribution to deposition improvement can be best understood from the simulations provided by Bechar et al. (1999) and by Dai and Law (1995). Generally, in air-assisted spraying the drag forces generated by the air jet transporting the spray dominates the travel of the cloud between the nozzle outlet and the target. At distances of a few millimetres from the target, where the air velocity is generally reduced to $<$1.0 m s^{-1}, electrostatic forces becomes dominant. A technique for improving penetration into the inner parts of plants and improving the coverage of inner foliage, while maintaining the coverage quality of the outer parts, was developed and verified in commercial field tests by Bechar, Gan-Mor, and