Spray and Atomization Technologies in Pesticides Application: A Review

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ABSTRACT

In the pesticides sprays, spray and atomization technologies to increase the deposition and reduce the drift are briefly reviewed.

Further research is needed to deduce a measure of drift risk in sprays with different structures, velocity profiles. For flat fan nozzles, the data of breakup length and thickness of liquid sheet are essential to understand the atomization processes and develop the transport model to target. In the air-assisted spray technology to reduce drift, further works on the effect of application height on drift and air assistance on droplet size should be followed. In addition, methods for quantifying included air in the air inclusion techniques are required. A few researches on the droplet size of fallout can be found in the literature. A combined technology with electrostatic method into one of method for the reduction of drift may be an effective strategy for increasing deposition and reducing drift.

Keywords: pesticides spray, electrospray, drift retardants, air-inclusion nozzle

INTRODUCTION

Pesticide applications to control agricultural diseases and pest are an important part of today's farming due to supply of the inexpensive and high quality product of many agricultural crops. However, the application of pesticides such as herbicide, insecticide and fungicide accompany contamination of surface and ground water, poisoning wild life, damage to non-target organisms, residue in foodstuffs and development of pesticide resistance.

The pesticide application in 1980 days

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was known as one of the most inefficient industrial process in world-wide use. The typical agricultural spray application generally results in spray deposition on less than 5 % of the target with approximately 1% of the applied pesticide eventually being biologically active against the target pest(Hilsop, 1987). Although current agrochemical application methods and equipment have improved application accuracy considerably than 1980 days, pesticides spray application remains an inefficient operation. The goal of pesticides spray application should be at first effective, the most effective form to the pest, secondly economical, at the lowest cost, thirdly, environmental, no off-target effects. Thus the challenge for the agricultural engineer is to produce the pesticide application sprayers that can control the volume distribution of spray droplets on a wide range of different target crops, and enable advantage to be taken of different pest control strategies without raising any new environmental contamination problems.

The objective of this paper is to provide an overview of current status in the spray and atomization technology of pesticides application, and future trends and needs will be presented.

AGROCHEMICAL SPRAYS

The sprayer in the pesticides application can be classified as the hand-held sprayers, boom sprayer, rotary sprayer, orchard sprayer and aerial sprayers, etc. The processes involved in agrochemical spray include pesticide selection and formulation, atomization, transport to target, impaction on plant surfaces, deposition, movement in/on surface, and biological effect.

The flow and spray characteristics of agrochemical sprayer which will influence spray drift and deposition are strongly affected by the physical properties such as density, viscosity and surface tension of the selected pesticide formulation. Agrochemical spray liquids are generally much more complex since they frequently contain adjuvants such as notably surfactant, emulsifiable oils, and polymers as retention enhancers and the different kind of drift retardants (Tominack, 2000).

The most factors that are influenced by atomization of agrochemical spray are the spray drift, the quantity and distribution of the deposit on the target and the uptake or mode of action of the agrochemical at the target surface. Various nozzles and sprayers are using for the agrochemical spray in the greenhouse, orchard and fields etc. Thus it is important to define nozzle performance because of its ultimate effect on the efficacy of the agrochemical application process. The droplet size and velocity characteristics of liquid sheet emerged from flat fan nozzles were studied in a wind tunnel in the presence of a non-uniform cross-flow by Farooq et al(2001). In addition, a numerical approach to relate the spray angle of a flat fan nozzle to its internal geometry was presented by Zhou et al.(1996). The generalized theoretical and semitheoretical equations for predicting the droplet size and velocity from pressure-swirl nozzle were suggested by Sidahmed(1996). The experimental data for the liquid sheet thickness and velocity are still required.

The transport of spray droplets to the plant is one of important processes in agrochemical sprays. The existing empirical and theoretical transport model (Sidahmed,1997) of spray droplets can not account for the entrainment of the surrounding air, drop-turbulence, evaporation, mutual interaction of the droplets in a spray such as collision and coalescence simultaneously. In particular, the existing models assume that a liquid jet breaks up immediately after leaving the nozzle and all droplet are formed at the nozzle tip. Therefore, the modification of existing models by introducing the expression for the breakup length of liquid sheet is required.

Droplet impaction and reflection is a function of surface tension and viscosity of agrochemical spray, droplet size and velocity, the surface morphology such as degree of pubescence, venation, fine structure, and chemistry of surface functional groups of the target surface(Spillman, 1984, Reichard, et al., 1986, Zhang and Basaran, 1997, Reichard et al.,1998)

The physicochemical properties of the plant cuticle influence the behaviour of spray droplets and, in turn, may affect the rate and efficiency of cuticle penetration(Kirkwood, 1999)

Droplet Size in Agrochemical Spray

The most widely used parameter of droplet size in the pesticides spray is the volume median diameter(VMD) measured in micrometer (Matthew,1992). A representative sample of droplets of a spray is divided into two equal parts by volume so that one half of the volume of the spray is in droplets larger than the value of the VMD, while the other half by volume is in smaller droplets. A few large droplets can account for a large proportion of the spray and so can increase the value of VMD, which on its own does not indicate the range of droplet sizes. This VMD, often expressed with $D_{v0.5}$ or $D_{0.5}$, is called as mass median diameter (MMD) by Lefebvre (1989), thus misleading the definition. The other widely used parameter of droplet size in the agricultural spray is the number median diameter(NMD). The NMD divide droplets into two equal parts by number without reference to this volume, thus emphasizing the small droplets.

The range of droplet size in the agricultural spray is usually expressed as VMD/NMD or span(relative span factor, relative diameter span factor). Because

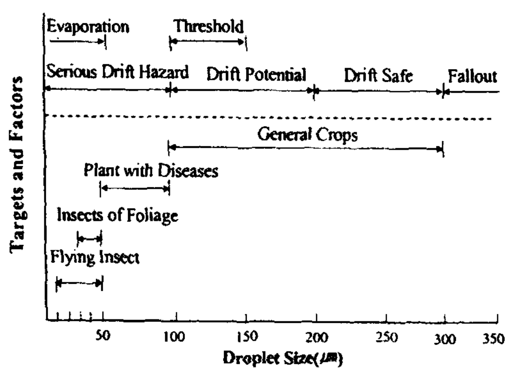

Fig. 1. Relationship between optimum droplet size ranges for selected targets and risk of drift

the value of VMD and NMD is affected by the proportion of large and small droplets, respectively, the ratio between these parameters is often an indication of the range of sizes, thus the more uniform the size of droplet the nearer is the ratio to 1. Sometimes the range of droplet size is expressed by the span in which the difference in the diameter for 90 % and 10 % of the spray by volume is divided by VMD($=(D_{0.9}\ \ D_{0.1})/D_{0.5}$).

International Spray Classification System have been established on the basis of nozzle classification methods which use droplet size distribution from reference nozzles as standards to define spray quality categories such as very fine, fine, medium, coarse and very coarse(Southcombe et al.,1997). In ASAE Standard X-572, extremely coarse is added in the spray quality categories (Womac, 2000).

One very important factor influencing drift is the size of the droplets sprayed. The relationship between optimum droplet size ranges for the selected targets and the risk of drift is shown in Fig. 1. As can be seen in Fig.1, there is no single best droplet size to optimize the selected target and pests. Research has shown that for greenhouse pesticides spray, it is recommended to produce

30-60μm VMD. For typical applications with boom type sprayers, droplets of 100 μm or less are considered highly to be driftable and droplets of 50μm or less completely evaporate before reaching the target. Yates et al.(1995) had reported that for fan and cone nozzles in a wind tunnel test, drops smaller than 150μm in diameter would generally pose the most serious drift hazard. Drop size in the range of 180 to 220μm is recommended for the pesticide applications in orchards and fields in case of wind speed of 0.5 to 4 m/s. However, Chapple et al.(1997) suggested for flat fan nozzle that droplets with diameter less than 150 μm are prone to drift and that drops > 300 μm had a low probability of being retained intact by plant surfaces. As shown in Fig. 1, the droplet size distribution within a spray is a major factor influencing drift and that the percentage of spray volume in droplet sizes below a defined threshold is a good indicator of the risk of drift. This threshold has commonly been taken as around 100μm(Miller, 1999,Piggott and Matthews, 1999). However, Walklate et al(1994) suggested that the % volume of droplets with diameters less than 100μm is not a good indicator of spray drift for agricultural boom sprayer applications. Thus, this will give misleading information when comparing the likely risk of drift from different nozzle types and/or when sprays have different velocity profiles, structures and entrained air profiles.

Increase of Deposition

The techniques to increase of deposition include the electrostatic based pesticide spray and spray with automatic techniques such as image analysis and optical sensors that are beyond of the scope of this article.

Electrospray: Electrostatic spraying of pesticides can improve not only the deposition efficiency, but also the spatial distribution of deposited droplet throughout the plant canopy, particularly underleaf where pests preferentially reside. This leads to significant advances in the research and development of electrostatic spraying technology for beneficial agricultural applications during the latter half of the 20^{th} century. The application of electrostatic pesticides spraying covers the hand-held sprayers, tractor mounted systems such as boom sprayers and rotary sprayers, orchard sprayers and aerial sprayers(Chang et al.,1995).

Charging methods of pesticides include

induction charging, ionised field charging(ionised-field corona-type charging), direct charging(contact charging), and combination charging of induction and ionised field charging(Splinter,1968). While the ionised filed charging method had shown limited promise for liquid pesticides, induction charging method gives more fully accomplishing results(Jahannama et al.,1999, Laryea and No, 2001, Laryea et al., 2001). In addition, Law (2001) had suggested that a hybrid aerodynamic-electrostatic spray system is most appropriate for outdoor trajection of charged-droplet clouds towards, and penetration into, three-dimensional plant canopies.

Factors affecting the deposition of electrostatic pesticide spray includes electrical conductivity and permittivity of liquids, electrical field gradient between the atomizer and the plant, space charge, image charge etc. An interesting and important limitation to the effectiveness of electrostatic spraying can arise due to ionisation at the surfaces of some crops which have sharply pointed leaves or hairs(Bailey, 1988). This problem can be removed by introducing the bipolar spray charging technique.(Cooper and Law, 1987).

Numerous experimental tests of electrostatic pesticides spraying technology by many researchers, both in the laboratory and the field, have generally verified 2-8 fold increases in deposition, as well as improved spatial distribution on plant surfaces, attributable to electrostatic forces (Law, 2001). However, there is a limitation that the droplet size should be of approximately 30-50μm VMD in order to ensure electrostatic forces dominating gravity for droplet charge-to-mass ratio values greater than around 2mC/kg.

In addition to the application of electrostatic pesticide spraying, electrohydrodynamic atomization(EHDA) technique was applied to develop a multiple EHDA nozzle for the application of pesticide in the greenhouse(Geerse et al., 2000).

Electrohydrodynamic spraying is the case in which the production of particles from a liquid is only due to the action of an electric field. Meanwhile, electrostatic spraying(electrospray) is the case in which a liquid is sprayed by pneumatic or other means and in which the application of an electric field has only the effect of charging the droplets and decreasing slightly their average size.

Reduction of Drift

The introduction of drift retardants into the formulations is one method of giving drift control by changing the physical properties of fluid sprayed. In addition, technical solutions by introducing the mechanical means have been developed. The nozzles with pre-orifice, air-assist, air inclusion, shield or shroud assist can be classified into the method for the reduction of drift.

Drift retardants: Pesticide formulations contain the active ingredient plus other chemicals such as adjuvants and drift retardants. Adjuvants are commonly added to pesticide formulations to enhance pesticide performance by serving several purposes such as wetting and emulsifications(Bode et al., 1976, Butler Ellis, and Tuck, 1999). Many spray drift retardants have been used to reduce off-target drift and improve the efficacy and performance of pesticides on the intended targets by increasing the mean droplet size(Zhu et al. 1997, Reichard, D.L. et al., 1993). While there are many commercially available drift retardants, only a few retardant active ingredients such as polyvinyl, polyethylene oxide and polyacrylamide are often used in the formulation of drift retardants.

The physical properties of fluid such as viscosity, density and surface tension are well known to affect the spray drop size distribution from a nozzle. For fluids with viscoelastic properties which are often contributed by dissolved polymers as the drift retardants, extensional viscosity has been recognized as an important factor in droplet size distribution. It is known that polymeric drift retardants can remarkably increase the extensional viscosity, and to a lesser extent, the viscosity of solutions, but they have little effect on either surface tension or density. The importance of extensional viscosity has stimulated research in the field of measurement of extensional viscosity and correlations with droplet size distribution.(Reichard & Zhu,1996, Mansor & Chigier,1995, Dexter, 1996, 2000).

Low-drift nozzle: The use of a pre-orifice in a flat fan nozzle design has been developed to reduce drift by creating a coarser spray quality, in other words, by reducing the fraction of droplets below around 100μm. Measurement of the droplet velocity profiles from low-drift nozzles show that droplets from this nozzle design travel more slowly than from a conventional flat fan design operating at the same pressures and flow rates(Miller 1999).

where they are mixed with a separate flow of compressed air. The droplets are then swept past the baffle plate where they are deflected off the flood tip into a 100 degree fan onto the target (McDonald,1990, Matthew, 1992). Some of the air is entrapped by the spray liquid to produce air-included droplets. The main use has been in the application of low volumes without too small an orifice liable to blockage. Spray drift from this nozzle was significantly lower than that obtained from flat fan nozzles. This twin fluid nozzle is not used at too higher air pressure than 1 MPa or very lower flow rates than 0.5 l/min, otherwise drift could be exacerbated. The incident of air inclusions was estimated by collecting the spray from the twin fluid nozzle in a petri dish containing a 5 mm layer of silicon fluid topped by 8-10 mm of oil. The droplets were inspected using a binocular microscope illuminated with cold light source(Combellack et al.,1996).

In the air induction or air infusion nozzle, the liquid being sprayed passes through a tapered nozzle which accelerates the liquid and projects the flow into the tapered mouth of the venturi. This creates a vacuum which causes air to be sucked in through the slots in the periphery of chamber. The mixture of air and liquid is compressed at it passes through chamber and is then sprayed through a flat fan nozzle. As same as with the twin fluid nozzle, drift from this nozzle was considerably lower than that obtained from the conventional nozzle. However, the holes on the side of the nozzle can draw in dust that may be suspended in the air and resulted in any type of plugging of nozzle, thus the additional filter will be required. The comparison of droplet size and drift potential between conventional, low drift, and air induction nozzles were presented by Bendig(1999). However, as pointed out by Miller and Butler Ellis(2000), techniques for quantifying included air are not well developed and further work is required to enable the density of droplets to be determined in-flight to improve our understanding of the operation of these types of air induction nozzles.

Shield or shroud assisted nozzle: The reduction of potential for drift has been accomplished by using some kind of shield or shroud to overcome the drift-producing air currents and turbulence that occur around the nozzle during spraying. Many researches had conducted both in the laboratory and field to quantify the effects of

The pre-orifice restrictor serves to reduce pressure and shifts the droplet spectrum towards larger droplets and reduces droplet velocity. The comparison of the effectiveness of low-drift nozzle without shield, which will be explained in the next section, with that of standard flat fan nozzles with a shield was carried out by Ozkan et al.(1997). The results showed that 0.61 l/min standard fat fan nozzle with a certain shield was more effective to reduce spray drift than low-drift nozzle without a shield.

Air-assisted nozzle: Basic concepts of air-assisted ground crop spraying are to increase spray drop velocity and control their trajectory so that deposition on plants is improved by introducing the air and thus problems of spray drift and soil contamination are reduced. The main parameters for air-assisted sprayer are: air speed, air jet angle, air flow rate, and height of spray release above the target crop. According to the variation of air speed, leaf coverage for the top, middle, and bottom parts of the canopy is widely different (Panneton et al.,2000). A vertical oriented air flow is less effective for coverage and produces more soil deposition than forward or backward angling, forward angling being the most efficient(Hilsop and Western, 1993). In addition, optimum air jet angle is different with air speed. There are relatively little recent data to give the effects of application height above the crop on the risk of drift. In addition, no research on the effect of air assistance on the spray characteristics, especially droplet size, can be found in the literature.

Air inclusion nozzle: Large droplet applications can significantly reduce the amount of drift but they can reduce deposition efficiency and pesticide effectiveness. However, the larger droplets from the air inclusion nozzles contain air bubbles within the droplets and burst on impact with the target. This improves the spread and adhesion of the pesticide which in turn allows the use of a coarser spray than usual which reduces drift and improves deposition efficiency. The air inclusion nozzles allow air to be mixed with liquid within the nozzle as the spray is produced, most commonly either by injecting air under pressure(twin fluid nozzle) or by drawing air in using a Venturi mechanism(air induction nozzle).

In the twin fluid nozzle, liquid from the spray tank is fed onto the baffle plate where it breaks into droplets. These are forced into the swirl chamber mechanical, pneumatic, porous, and solid shields on drift. Most of studies indicate that most of these device reduce off-target spray drift(Smith et al. 1982, Furness, 1991). However, the results vary remarkable from one study to another due to varying atmospheric conditions in the field experiment. Nine different shields tested by Ozkan et al.(1997) in a wind tunnel concluded that a double-foil shield produced the best deposition result. The shield assisted spraying technique have been considered as economically viable alternatives to expensive air-assisted sprayers.

The combined technology with shield assisted nozzle into electrospray had been investigated by Lake et al(1982). They carried out the effect of a shield on the penetration of electrically charged and uncharged droplets into barely in the laboratory using real plants. Their results showed that there was more deposits on targets, both with charged and uncharged spray, when a shield was employed. However, they indicated that there was a problem with the charged spray being attracted to, and deposited on the shield.

The shielded system for orchard sprayer is called as the recycling air-assisted tunnel sprayer or shielded recycling sprayer. The most important advantage of this sprayer is an outstanding reduction of emission to the environment(50% by Doruchowski and Holownicki, 2000), considerable saving of chemicals(20-30% by Ade and Pezzi, 2001), and safety of operator, attributable to recycling capability and confinement of spray. However, the shielded recycling sprayer can be used only in dwarf and semi-dwarf orchard and are not readily adopted or modified for use on slopes and in multi-row systems.

FUTURE RESEARCH CHALLENGES

Space has limited brief reviews of only a portion of research and development of agricultural spray application. Likewise omitted have been significant advances of measurement techniques of droplet size and velocity, aerial spray and spray modelling, especially CFD code etc. Further research challenges in electrostatic crop spraying was summarized in detail by Law(2001).

It is not currently technically feasible to accurately deduce a measure of drift risk such as < 100 μm or < 150 μm in sprays with different structures, velocity profiles etc. In addition, a few research on the droplet size of fallout can be found in the literature. In the pesticides spray, the researches on the measurement of liquid sheet thickness and breakup length of liquid sheet are essential to understand the atomisation processes and to develop the transport model to target.

In the air-assisted spray technology to reduce drift, further works on the effect of application height on drift and air assistance on droplet size should be followed. In addition, methods for quantifying included air in the air inclusion techniques are required. A combined technology with electrostatic method into one of method for the reduction of drift may be an effective strategy for increasing deposition and reducing drift.

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