

DROPLET-SIZE CHARACTERIZATION OF HANDHELD ATOMIZATION EQUIPMENT TYPICALLY USED IN VECTOR CONTROL¹

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ABSTRACT. The atomization characteristics of 4 handheld sprayers (Leco P-1, Colt ULV Aerosol Generator, ULVAFAN MK2, Turbair ElectraFan 12) and a Stihl SR400 backpack sprayer were evaluated with the use of water- and oil-based solutions. The effects on droplet-size spectrum (i.e., droplet size) for 3 insecticides (Tempo SC Ultra®, Anvil 10+10®, and Aqua-Reslin®) were also evaluated. Generic solutions were used to simulate the physical properties of the active-ingredient solutions in some tests. Significant differences were observed in the droplet spectrum generated by the different sprayers. The volume median diameter of the equipment tested ranged from 14.9 to 90.5 μm for the water-based solutions and from 11.7 to 92.4 μm for the oil-based solutions. The Colt ULV sprayer was the only one tested that complied with label requirements for aerosols, yielding acceptable $D_{v0.5}$ values of 14.9–16.0 μm with water-based Aqua-Reslin and 14.1 μm with Anvil 10+10. The information presented will allow equipment operators to make an informed decision when selecting equipment and operational parameters.

KEY WORDS Atomization, droplet size, sprayer, hand-held sprayer, vector control

INTRODUCTION

Although there have been numerous studies to determine the optimum or best droplet size to maximize vector control efforts (Himel 1969, Lofgren et al. 1973, Curtis and Beidler 1996, Crockett et al. 2002), fewer studies have detailed specific droplet-size spectra for specific equipment (Younglove and McCool 1994, Brown et al. 1998). Droplet size can be measured with water-sensitive cards (Hoffmann and Hewitt 2005), TeflonTM or magnesium oxide slides (Mount et al. 1970, Meisch et al. 2005), laser-based systems (Picot et al. 1985, Young 1986), or hot-wire systems (Brown et al. 1998). Numerous researchers have also evaluated specific products for their efficacy on controlling different species of mosquitoes (Inman et al. 1997, Ham et al. 1999, Crockett et al. 2002). Electrostatic nozzles generate charged droplets that have been found to increase deposition on both plants (Coffee 1979) and artificial targets (Lane and Law 1982). Electrostatic nozzles were found to increase adult mortality and deposition on cages under aerosol treatment conditions (Ham et al. 1999).

The physical properties of the spray solution, such as viscosity and dynamic surface tension, have long been recognized as one of the dominant factors controlling atomization of a liquid (Threadgill et al. 1975, Bouse et al. 1990).

Therefore, applicators must be aware of the physical characteristics of applied materials and how changes in spray-solution physical properties, which can be caused by dilution, affect spray droplet-size spectra.

When comparing the results presented in this manuscript to previously reported results, there are several factors to consider. Most available literature related to droplet-size assessment reports only results from Teflon-coated or magnesium oxide slides. These slides were generally placed at distances of 3–10 m from the sprayer and may or may not have been placed on a rotating mechanism. The distance from the sprayer has a significant effect on the droplets measured. Droplets that are greater than 50 μm are generally not considered aerosol droplets; therefore, these droplets have a great propensity of “settling out” or depositing on the ground before reaching a slide located 3–10 m from the sprayer. Settling out of the large droplets biases the droplet spectrum results toward smaller droplets measured by samplers placed away from the sprayer. Droplets that remain in the air, particularly those <15 μm , can have low collection efficiencies onto samplers (Rathburn 1970) and may be undersampled by slide analyses methods. Although most of the equipment evaluated in these studies produce aerosol droplets, others can be used in making barrier treatments, i.e., larger droplets. The equipment was selected based on its ability to be carried by 1 person and not the type of spray droplet spectra it produced, as this was not known prior to these studies. The objective of this study was to use a laser-based droplet analysis system to evaluate the droplet spectrum characteristics generated by several handheld atomization systems for water- and oil-based formulations.

¹ Mention of a trademark, vendor, or proprietary product does not constitute a guarantee or warranty of the product by the USDA or US Navy, and does not imply its approval to the exclusion of other products that may also be suitable.

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Fig. 1. Testing of handheld atomizer equipment showing a vertical traverse of the spray plume from the atomizer through the laser beam of the droplet-sizing system.

MATERIALS AND METHODS

Thirty-five (35) replicated spray tests, comprised of 5 atomizers and 7 spray formulations, were completed for this study over a 2-day period. Four handheld sprayers and 1 backpack sprayer were selected from equipment that is commonly used for vector and flying insect control applications. The 7 formulations were divided into 2 groups, water or oil based. Because of time constraints and logistical considerations, every combination of sprayer and formulation could not be tested. The specific testing protocol, spray formulations, equipment tested, and physical property measurement procedures are discussed in the following sections.

Testing protocol

For each combination of handheld atomizer and spray formulation, 3 independent replications were conducted. A replication is comprised of operating the atomizer for 30 sec at a distance of 30 cm (12 in.) from the laser beam of the droplet measuring system. During the 30 sec, the spray plume emitted by the atomizer was moved vertically up and down so that the entire spray plume traversed the laser beam 3 times (Fig. 1). Appropriate personal protective equipment, such as respirators, gloves, goggles, and Tyvek suits, were worn during all tests containing active ingredients.

Droplet-sizing system

A Sympatec Helos laser-diffraction droplet-sizing system (Sympatec Inc., Clausthal, Germany) was utilized in this study. The Helos system uses a 623 nm He-Ne laser and was fitted with an R5 lens, which made the dynamic size range from 0.5 to 875 μm in 32 sizing bins. The most common term used to describe spray droplet-size spectra is volume median diameter

($D_{V0.5}$), which is the droplet diameter (μm) where 50% of the spray volume or mass is contained in droplets smaller than this value. $D_{V0.1}$ and $D_{V0.9}$ values, which describe the proportion of the spray volume (10% and 90%, respectively) contained in droplets of the specified size or less, were also measured. Because droplets 50 μm and smaller are generally considered to be aerosol droplets (Matthews 1988), the percent of spray volume contained in droplets less than 52 μm (%vol <52 μm) was calculated for all tests. The 52- μm value was selected because it is a definitive edge in one of the sizing bins used in the Helos software package. The term (%vol <52 μm) allows the user of this equipment to determine the portion of the applied material that will most likely stay aloft after an application and potentially impinge on a flying insect.

The Army Insecticide Measuring System (KLD Labs, Inc., Huntington Station, NY) was not available during this study. This system is commonly used in making droplet-size measurements of vector control equipment. The authors hope to incorporate this instrument in future studies.

Spray formulations

Seven different spray formulations (Table 1) were evaluated. The active-ingredient formulations were selected by choosing products that are commonly used in vector control scenarios in the USA. The products used were Aqua-Reslin® (Permethrin and Piperonyl Butoxide, Bayer Environmental Science, Montvale, NJ), Tempo SC Ultra® (β -Cyfluthrin, Bayer Environmental Science, Montvale, NJ), and Anvil 10+10® (Sumithrin, Clarke Mosquito Control Products, Roselle, IL). Dilution and flow rates utilized in these tests were similar to those recommended by the manufacturers for mosquito control by aerosol or ultra-low volume (ULV) applications. Two of the solutions are used as mimics of real-world solutions. There were 2 main purposes for testing mimics. The 1st was to limit the use of active ingredients at the test site. The 2nd reason was to evaluate the mimics as possible spray solutions that could be used during calibration of spray equipment. This would greatly limit worker exposure during calibration procedures and reduce site contamination at locations where sprayers are routinely calibrated. These mimics or generic sprays are further discussed in the Results and Discussion section.

Equipment

The 5 handheld atomizers evaluated in these tests are detailed below.

Colt ULV Aerosol Generator (London Fog, Inc., Long Lake, MN): The system is handheld and is powered by a Fox F-7 2-cycle engine. The

Table 1. Spray formulations and dilution rates used in the atomization studies.

Formulation	Description	Rate added to 1 liter of water ¹
Triton X-100	Water solution with Triton X-100 at 0.1% v/v	37.8 ml
Tempo SC Ultra®	Water solution with Tempo SC Ultra at 0.03% v/v	3.2 ml
Aqua-Reslin® 1:44	Water solution with Aqua-Reslin at 2.2% v/v	22 ml
Aqua-Reslin 1:1	Water solution with Aqua-Reslin at 50% v/v	500 ml
Aqua-Reslin 1:3	Water solution with Aqua-Reslin at 25% v/v	250 ml
BVA ULV Oil 13	Oil solution with only BVA ULV Oil 13	n/a
Anvil 10+10®	Oil solution with only Anvil 10+10	n/a

¹ n/a, not applicable (no water added to mixtures).

Colt weighs 19 lb (8.6 kg). Flow-rate metering is done by orifice discs (Nos. 16, 22, and 24). The No. 16 orifice was used to provide a flow rate of ca. 1 fl oz/min (29 ml/min).

Leco P-1 (Lowndes Engineering Co., Valdosta, GA): This blower-pressurized system is handheld and is driven by a Robin 2-cycle engine with a net weight of 17 lb (7.7 kg). It has 4 adjustable flow rate settings (1/4, 1/2, 3/4, and full). The equipment was set at the 1/2 setting to provide a ca. 1 fl oz/min (29 ml/min) flow rate.

Stihl SR400 backpack sprayer and duster (Stihl, Waiblingen, Germany): This is a backpack mist-blower powered by a 2-cycle STIHL engine. It has a net weight of 24.0 lb (10.9 kg). The sprayer has 6 metering nozzle settings to adjust flow rate. When all 6 settings were utilized, the 1 setting provided a ca. 1 fl oz/min (29 ml/min) flow rate.

Turbair ElectraFan 12 (Micron Sprayers Ltd., Bromyard, Herefordshire, UK): This is an air-assisted spinning-disc controlled droplet application system powered by a 12-V DC battery. The system with a full bottle weighs 7.2 lb (3.25 kg). The battery weighs 14.5 lb (6.6 kg). Flow-rate metering is done by feed nozzles (0.9, 1.1, 1.3, 1.4, 1.6, and 2.0 mm orifice diameters). The 0.9 nozzle was used to deliver a flow rate of ca. 1 fl oz/min (29 ml/min).

ULVAFAN, Dram Model MK2 (Micron Sprayers Ltd.): The ULVAFAN is a handheld, air-assisted spinning-disc spray system. It is powered by a 12-V DC battery. Flow metering is done by feed nozzles (4 color-coded nozzles). The orange nozzle was used to provide a flow rate of ca. 1 fl oz/min (29 ml/min).

Two additional tests were conducted with the use of an air-assisted electrostatic nozzle (Spectrum Electrostatic, Inc., San Antonio, TX) fitted onto the outlet of the Stihl 400. There are no 1–6 settings for the spray outlet once the electrostatic nozzle is placed on the Stihl 400. This nozzle inducts an electrostatic charge onto the spray droplets. Brown et al. (1997) reported a $D_{v0.5}$ for the Spectrum Electrostatic nozzle of 51.7 μm when the nozzle was fitted to a Hudson Porta-Pak® sprayer.

Physical property measurements

Dynamic surface tension was measured with a SensaDyne Surface Tensiometer 6000 (Chem-Dyne Research Corp., Mesa, AZ) with the use of the maximum bubble pressure method. The gas flow-rate settings were varied until surface age values less than and greater than 0.02 sec were found. Then, a table of percent flow-rate settings was built in 5% increments to include the previous settings. This table was calibrated with the use of 100% ethanol and pure water. The probes were lowered into the sample and the dynamic surface tension, bubble rate, bubble age, and temperature were measured at each setting in the table. The dynamic surface tension at 20 msec was linearly interpolated from the results. The tests were replicated 3 times.

Viscosity of each of the spray solutions was measured with a Brookfield Synchro-Lectric Viscometer (Model LVT, Brookfield Engineering, Middleboro, MA) with the use of a UL adapter 0.1–100 cps range. The spindle was inserted into the sample. The motor was started and run until the dial reading stabilized and the reading was recorded.

RESULTS AND DISCUSSION

The physical properties and drople-sizing results for water-based and oil-based sprays are presented, followed by a comparison of previously reported results to this study's results.

Physical properties

The physical properties of a spray are one of the most important factors that affect atomization of a spray (Butler et al. 2001). Because a large number of tests were conducted in this study, it was desirable to use solutions that mimicked active-ingredient sprays but did not contain active ingredients to limit the exposure of the testing personnel and the environment to these active ingredients. The physical properties of all the solutions tested are shown in Table 2, where water is listed only as a reference. The addition of Triton X-100 at a 0.1% rate to water was found

Table 2. Physical properties of spray solutions tested.

Spray solution	Dynamic surface tension (mN/m @ 20 msec)	Viscosity (cP @ 20°C)
Water	73	1.0
0.1% Triton X-100	48.1	1.1
Tempo SC Ultra®	72.8	1.1
Aqua-Reslin® 1:44	49.7	1.1
Aqua-Reslin 1:1	38.6	9.0
Aqua-Reslin 1:3	40.5	1.3
BVA 13 ULV Oil	33.9	17.1
Anvil 10+10®	34.4	13.9

to mimic the physical properties of the Aqua-Reslin solution except for the 1:1 dilution, which had a much higher viscosity. Because only 3.2 ml of the Tempo SC Ultra were added to the spray solution, there was a very minimal change of the physical properties as compared to water. BVA 13 ULV Oil (Adapco, Inc., Sanford, FL) had physical properties very similar to Anvil 10+10.

Water-based sprays atomization results

There was a wide range in droplet spectrum generated by the spray equipment tested for the water-based spray solutions (Table 3). The Colt ULV sprayer generated the smallest $D_{V0.5}$ (14.9 μm), whereas the ULVAFAN sprayer generated the largest $D_{V0.5}$ (90.5 μm). The Triton X-

100 solution had essentially the same atomization characteristics as the Aqua-Reslin solutions. The settings (1–6) on the Stihl SR400 control the flow rate and had a significant effect on the droplet atomization properties with droplet size increasing as the flow rate increased. The 71.1- μm $D_{V0.5}$ for the electrostatic nozzle was higher than the previously reported value of 51.7 μm ; however, a different backpack unit was tested in this study.

Although the Tempo SC Ultra product label does not specify droplet-size requirements, the Aqua-Reslin product label specifically states that the “optimum droplet size range is from 8 to 30 microns by the volume median diameter (VMD) calculation.” The Colt ULV sprayer was the only piece of equipment to meet this recommendation.

Oil-based sprays atomization results

A wide range in droplet spectra was generated by the different spray equipment for the oil-based spray solutions (Table 4). The Colt ULV sprayer generated the smallest $D_{V0.5}$ (11.7 μm), whereas the ULVAFAN sprayer generated the largest $D_{V0.5}$ (92.4 μm). The BVA 13 ULV Oil solution had essentially the same atomization characteristics as the Anvil 10+10 solutions. With the Stihl SR400 set at setting 6, the BVA 13 ULV Oil solution produced a $D_{V0.5}$ and a %vol < 52 μm of

Table 3. Atomization parameters for water-based sprays.

Sprayer	Spray solution	$D_{V0.1}$ ($\mu\text{m} \pm \text{SD}$)	$D_{V0.5}$ ($\mu\text{m} \pm \text{SD}$)	$D_{V0.9}$ ($\mu\text{m} \pm \text{SD}$)	%vol < 52 μm
Colt ULV	Aqua-Reslin® (1:1)	9.7 $\pm$ 1.8	16.0 $\pm$ 1.6	26.7 $\pm$ 2.2	99.2
Colt ULV	Aqua-Reslin (1:3)	9.6 $\pm$ 1.6	14.9 $\pm$ 0.6	23.3 $\pm$ 3.0	99.9
Leco P-1	Aqua-Reslin (1:1)	33.6 $\pm$ 1.9	75.3 $\pm$ 6.3	137.3 $\pm$ 5.8	25.3
Leco P-1	Aqua-Reslin (1:3)	32.6 $\pm$ 3.5	71.8 $\pm$ 4.6	113.1 $\pm$ 6.0	26.2
Stihl SR400					
Setting 1	0.1% Triton X	18.0 $\pm$ 0.3	52.1 $\pm$ 0.8	102.6 $\pm$ 2.5	50.5
Setting 2	0.1% Triton X	21.0 $\pm$ 0.2	60.0 $\pm$ 0.3	118.4 $\pm$ 1.4	42.0
Setting 3	0.1% Triton X	23.6 $\pm$ 0.4	67.6 $\pm$ 1.2	138.1 $\pm$ 3.6	35.9
Setting 5	0.1% Triton X	25.5 $\pm$ 1.1	74.1 $\pm$ 3.3	160.9 $\pm$ 1.5	32.0
Setting 6	0.1% Triton X	27.2 $\pm$ 1.2	78.5 $\pm$ 2.9	166.3 $\pm$ 8.8	29.4
Stihl SR400					
Setting 1	Tempo SC Ultra®	22.4 $\pm$ 0.6	62.1 $\pm$ 1.0	122.4 $\pm$ 2.5	40.3
Setting 4	Tempo SC Ultra	30.0 $\pm$ 0.3	83.5 $\pm$ 0.3	159.0 $\pm$ 0.5	26.1
Setting 6	Tempo SC Ultra	31.6 $\pm$ 0.2	89.3 $\pm$ 0.5	184.8 $\pm$ 3.5	23.4
Stihl SR400					
Setting 1	Aqua-Reslin (1:1)	20.9 $\pm$ 1.2	49.9 $\pm$ 0.2	98.3 $\pm$ 2.0	53.4
Setting 1	Aqua-Reslin (1:44)	16.5 $\pm$ 0.9	45.6 $\pm$ 1.3	81.8 $\pm$ 3.7	59.9
Setting 4	Aqua-Reslin (1:44)	28.2 $\pm$ 0.6	76.2 $\pm$ 1.6	137.3 $\pm$ 1.4	29.1
Setting 6	Aqua-Reslin (1:44)	30.0 $\pm$ 0.15	81.2 $\pm$ 0.4	152.5 $\pm$ 3.1	26.6
Stihl SR400 with electrostatic nozzle	Aqua-Reslin (1:44)	26.2 $\pm$ 0.1	71.1 $\pm$ 0.4	126.9 $\pm$ 1.4	31.6
Turbair Electrafan	0.1% Triton X	33.3 $\pm$ 1.1	47.2 $\pm$ 0.9	74.4 $\pm$ 2.2	64.6
ULVAFAN	0.1% Triton X	36.7 $\pm$ 4.1	63.3 $\pm$ 5.3	117.4 $\pm$ 4.3	32.0
ULVAFAN	Tempo SC Ultra	59.0 $\pm$ 5.5	90.5 $\pm$ 5.6	123.7 $\pm$ 4.6	6.2

Table 4. Atomization parameters for oil-based sprays.

Sprayer	Spray solution	D _{v0.1} ($\mu\text{m} \pm \text{SD}$)	D _{v0.5} ($\mu\text{m} \pm \text{SD}$)	D _{v0.9} ($\mu\text{m} \pm \text{SD}$)	%vol < 52 μm
Colt ULV	BVA 13 ULV Oil	3.2 $\pm$ 1.1	11.7 $\pm$ 1.7	28.6 $\pm$ 6.8	99.3
Leco P-1	BVA 13 ULV Oil	11.9 $\pm$ 0.4	49.3 $\pm$ 1.0	101.9 $\pm$ 9.4	53.6
Stihl SR400					
Setting 1	BVA 13 ULV Oil	9.4 $\pm$ 1.8	36.9 $\pm$ 2.2	90.4 $\pm$ 4.9	66.4
Setting 2	BVA 13 ULV Oil	15.6 $\pm$ 0.1	55.8 $\pm$ 0.4	109.9 $\pm$ 2.7	46.9
Setting 3	BVA 13 ULV Oil	21.9 $\pm$ 0.8	73.2 $\pm$ 11.2	265.9 $\pm$ 18.5	35.1
Setting 4	BVA 13 ULV Oil	21.5 $\pm$ 0.6	71.3 $\pm$ 2.9	142.4 $\pm$ 11.9	34.9
Setting 5	BVA 13 ULV Oil	22.5 $\pm$ 0.8	76.2 $\pm$ 4.5	156.0 $\pm$ 16.2	32.8
Setting 6	BVA 13 ULV Oil	23.1 $\pm$ 0.4	76.8 $\pm$ 2.1	165.7 $\pm$ 11.4	31.9
Turbair Electrafan	BVA 13 ULV Oil	37.5 $\pm$ 7	84.3 $\pm$ 1	116.8 $\pm$ 4.4	18.4
ULVAFAN	BVA 13 ULV Oil	36.6 $\pm$ 17.6	92.4 $\pm$ 44.5	225.2 $\pm$ 47.1	26.4
Colt ULV	Anvil 10+10®	7.8 $\pm$ 0.2	14.1 $\pm$ 0.1	27.2 $\pm$ 2.0	99.4
Leco P-1	Anvil 10+10	14.4 $\pm$ 0.1	51.5 $\pm$ 2.2	95.0 $\pm$ 5.1	51.3
Stihl SR400					
Setting 1	Anvil 10+10	6.0 $\pm$ 2.6	33.4 $\pm$ 4.1	83.5 $\pm$ 3.1	70.2
Setting 4	Anvil 10+10	22.1 $\pm$ 0.1	70.0 $\pm$ 0.3	138.1 $\pm$ 0.3	35.2
Setting 6	Anvil 10+10	23.6 $\pm$ 0.6	74.0 $\pm$ 1.3	147.7 $\pm$ 2.94	32.7
ULVAFAN	Anvil 10+10	38.5 $\pm$ 5.2	81.3 $\pm$ 3.2	111.7 $\pm$ 3.6	20.2

76.8 μm and 31.9%, respectively, while the Anvil 10+10 solution produced a D_{v0.5} and a %vol < 52 μm of 74.0 μm and 32.7%, respectively.

The Anvil 10+10 label states that when the product is used with portable ULV sprayers the recommended droplet size is "in the 5 to 25 micron range." As seen in the previous results, the Colt ULV sprayer was the only one that met this label requirement.

CONCLUSIONS

The atomization characteristics from 5 hand-held sprayers were evaluated with the use of water- and oil-based solutions. There were significant differences in the droplet spectrum generated by the different sprayers. Generic solutions were used to simulate the physical properties of some of the active ingredient solutions. The volume median diameter of the equipment tested ranged from 14.9 to 90.5 μm for the water-based solutions and from 11.7 to 92.4 μm for the oil-based solutions. The electrostatic nozzle, which was fitted onto the Stihl 400, produced a droplet spectrum similar to many of the other sprayers tested. The atomization data in this manuscript will aid equipment operators in making an informed decision when selecting equipment and operational parameters.

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