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OPERATIONAL NOTE

INDOOR LOW-VOLUME SPRAY TRIALS: HANDHELD EQUIPMENT EVALUATION[1]

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ABSTRACT. Four handheld aerosol–mist generators and 1 thermal fog generator were evaluated initially for their ability to deliver low flow rates (≤5 ml/min) of resmethrin insecticide. Two generators, the London Fog Eliminator® and Clarke P1®, were then selected from that group to conduct a treatment of a block of 16 residences (4 × 4 grid) vs. direct treatment of individual residences to determine the most efficacious method of treating a group of small dwellings or a village. Data are presented on droplet density, volume median diameter, and mortality of caged mosquitoes treated with the P1 and Eliminator in residences treated as a group; and mortality for caged *Aedes aegypti* L. in residences treated individually with the P1 at various flow control settings and spray-on times.

KEY WORDS Low-volume spray, *Aedes aegypti,* handheld sprayer

Interior application of aerosolized insecticide is a critical component of many public health programs designed to reduce the incidence of arthropodborne disease (e.g., malaria, dengue fever, or Chagas disease). Although the World Health Organization recommends intermittent or continuous hand-operated aerosol generators or mist blowers for interior space spraying, the choice of equipment is ultimately dependent on many factors (e.g., product reliability, ease of transport and operation, pesticide formulation, cost, and so on). For example, limited economic resources often direct product choice. Therefore, research efforts have concentrated on developing economically efficient, scenario-specific application technology that uses a variety of equipment designs and pesticide formulations and concentrations (Anonymous 1995). Additionally, treatment area specifications also influence product choice. Some sites are not easily accessed with equipment designed exclusively for insecticide deposition. Specifically, a spray may have to be projected into the eaves of a building or through doorways where ingress or removal of furniture is difficult. Insecticide applications at disease vector resting sites located in dense vegetation also may be hampered.

Equipment characteristics and insecticide aerosol mist dynamics in field application scenarios have been examined by several workers (Anonymous 1990). Gratz and Dawson (1963) documented the distribution of fenthion applied in domiciles and showed the effect of walls and ceilings on deposition. Furthermore, Ware and Cahill (1978) described the dynamics of emulsion spray movement when applied in a room. Winnett and Siewierski (1975) demonstrated the movement of pesticides between buildings after an aerosol application. Self et al. (1976) demonstrated that bioresmethrin applied by backpack sprayer at 0.05 ml/min and 2.1 droplets/cm^2 caused a 38% mortality in an *Aedes aegypti* (L.) adult population. Finally, Bown et al. (1981) demonstrated that technical-grade malathion applied as an aerosol mist in 2 sequential applications by backpack sprayer resulted in long-term control of *Anopheles* spp. and *Aedes* spp.

In this study, 5 different handheld pesticide sprayers were compared initially by using 1 pesticide (Scourge™: resmethrin 4.0%, piperonyl butoxide 12.4%; Aventis Environmental Science, Montvale, NJ) to determine the minimal flow rate required to produce the greatest mosquito mortality. Because resources often limit mosquito control operations in different locations around the globe, information concerning efficient use of pesticide with these devices would be beneficial. These limited resources would include equipment and formulation, and each should be used efficiently.

Four handheld aerosol–mist generators and 1 thermal fog generator were examined for the capacity of delivering low flow rates (≤5 ml/min) of insecticide (Tables 1 and 2). The machines were an Eliminator® and a Colt® (London Fog, Inc., Long Lake, MN), a P1® (Clarke Mosquito Control, Roselle, IL), a G3® (Micro-Gen, San Antonio, TX), and a Mighty Moe® (Buffalo Turbine Mfg. Co., Gowanda, NY). A subsequent study to determine the lowest flow rate that would achieve the greatest mortality was then conducted (Table 3). This was then followed up by a test conducted to treat a mock village.

Mosquito bioassay cages were constructed of 3.8

[1] The opinions and assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

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Table 1. Flow rates and volume median diameters for selected handheld aerosol equipment and BVA no. 13 oil.[1]

Machine	Flow rate setting	Air temperature (°C)	Flow rate (ml/min ± SD)	Volume median diameter (μm ± SD[1])
Mighty Moe[2]	½	29	165 ± 7.0	63 ± 10
	1	29	340 ± 28	44 ± 2.0
Colt[3]	16	29	29 ± 0.6	16 ± 2.0
	22	29	56 ± 0	19 ± 0.7
	24	29	62 ± 0.1	26 ± 2.0
P1[4]	¼	29	3 ± 0.1	18 ± 1.0
	½	29	11 ± 0.9	21 ± 4.0
	¾	29	24 ± 0.3	24 ± 0.8
	1	29	37 ± 0.6	28 ± 4.0
G3[5]	1	27	30 ± 0	10 ± 1.0
	2	27	30 ± 0	13 ± 0.8
	3	27	100 ± 0	14 ± 2.0
Eliminator[3]	1	27	261 ± 5.0	21 ± 1.0

[1] Two replications.
[2] Buffalo Turbine Mfg. Co., Gowanda, NY.
[3] London Fog, Inc., Long Lake, MN.
[4] Clarke Mosquito Control, Roselle, IL.
[5] Micro-Gen, San Antonio, TX.

Table 3. Flow rate and mortality data with the Clarke P1 and Scourge.[1]

Spray time (sec)	Flow rate setting	Amount applied (ml)	Total mosquitoes[2]	No. dead	% mortality
5	1	0.3[3]	164	20	13
10	1	0.5[3]	162	89	55
15	1	0.7[3]	161	118	74
25	1	1.2	160	140	88
30	1	1.4	163	162	99
5	2	0.5[3]	162	162	100
10	2	1.0	168	168	100
15	2	1.5	164	156	97
15	3	5.5	163	163	100
Control	0	0	313	1	0.3

[1] Two replications.
[2] Calculated.
[3] Output erratic at this low flow rate.

× 10.2-cm-inner diameter polyvinyl chloride (PVC) pipe covered with nylon tulle held in place by PVC bands. Cages were hung vertically at a height of 1 m in the domicile at each interior corner.

Mosquitoes were colony-reared, adult, 3- to 5-day-old, nonbloodfed female *Ae. aegypti.* The colony originated from eggs of an insecticide-susceptible colony at the USDA Medical Entomology Laboratory in Gainesville, FL. Bioassay cages contained approximately 25 adult female mosquitoes. Caged mosquitoes were held in an ice chest lined with moist paper towels until used. After exposure, mosquitoes were returned to the laboratory and transferred to clean holding cages made of 0.24-liter paper cartons with nylon tulle covers. Mosquitoes in these holding cages were kept in an ice chest for 24 h and offered a 10% sugar solution on polyester fiber balls; mortality was recorded 24 h after spray exposure. Maximum and minimum temperatures were recorded inside the chest during the holding period so radical changes in temperature would be noted.

Aerosol droplets were also collected with rotating slide holders (John W. Hock Company, Gainesville, FL) by using Teflon®-coated slides. Fifteen minutes were allotted for the aerosol cloud to disperse over caged mosquitoes. Each slide was then sealed in a standard slide box and read within 4 h. Slides not read within 4 h were covered with a paper gasket, an additional plain glass slide, and taped to prevent evaporation of the insecticide (Anonymous 1985) and read within 1 wk. Variances between the slides read within 4 h after exposure and those not read until the next week were similar; therefore, results for the 2 groups were pooled. Droplets were collected between 1000 and 1500 h for all replications under the following environmental conditions: relative humidity 45–80%, wind speed 3.2–8.1 kph, and ambient temperature 24–28°C. A minimum of 100 droplets was measured on each slide with a compound microscope. The

Table 2. Flow rate (ml) tests on selected handheld aerosol generators and Scourge.[1]

Machine	Flow rate setting (orifice)	Time (sec ± SD) 5	10	15	30
Colt	16	5.0 ± 0	7.0 ± 0	9.0 ± 0	15.0 ± 0.6
	22	9.0 ± 0.6	13.0 ± 0	17.0 ± 0	28.0 ± 0
	24	9.0 ± 0.6	14.0 ± 0	18.0 ± 0.6	31.0 ± 1.0
P1	1	0.25 ± 0	0.5 ± 0	0.7 ± 0.4	1.0 ± 0.1
	2	0.5 ± 0	1.0 ± 0	1.5 ± 0.2	5.0 ± 0.9
	3	2.2 ± 0	4.0 ± 0	6.0 ± 0.5	12.0 ± 0.3
	4	2.3 ± 0	5.0 ± 0	10.0 ± 0.3	19.0 ± 8.0
Eliminator	1	22.0 ± 0.6	43.0 ± 0	62.0 ± 2.0	131.0 ± 8.0

[1] Three replications.

Table 4. Mortality and droplets/cm² (±SD) for the Clarke P1 and an Eliminator thermal fogger sprayed into domiciles.[1]

Distance domicile located downwind from the spray source (m)	P1		Eliminator	
	Droplets/cm²	Mortality (%)	Droplets/cm²	Mortality (%)
0	852 ± 383	71 ± 14	858 ± 463	100
3.6	351 ± 319	0	159 ± 125	25 ± 11
7.2	160 ± 154	0	21 ± 10	1 ± 1
10.8	134 ± 132	0	21 ± 20	4 ± 1
Control	0	0	0	0

[1] Two-second spray time, 4 replications, ≤5 ml/min.

number of droplets occurring per square centimeter was calculated as described in Brown et al. (1993). Volume median diameter, correlation coefficients, and confidence intervals were calculated and are presented where appropriate.

Flow rates were measured with standard graduated cylinders (Tables 1–3) but the actual technique varied from machine to machine because of differing engineering designs. Regardless, the flow rate of each machine was measured over a period of 5, 10, 15, 30, and 60 sec.

Tests were conducted in a mock village at the International Center for Public Health Research near McCellanville, SC. The village consisted of 16 one-room residences measuring 3.7 × 4.9 × 3.7 m high fitted with a gabled roof. The residences were wooden frame structures covered with chipboard. The roofs were galvanized steel. Each residence had two 0.6-m square windows 1.2 m from the base of the 4.9-m walls and 2.4 m from diagonal corners so that the windows were slightly offset from each other. Two doors measuring 0.9 × 2.0 m were located in diagonal corners of the 3.7-m walls. The domiciles were arranged in 4 rows of 4, and were separated by 1.2 m from side to side and 3.1 m front to back. Cages were suspended from nails in the wall of the domicile's wooden frame. For each series of tests, 4 control cages were also placed in a remotely located domicile or, if the test domiciles had been sprayed that week, controls were placed in the test domiciles for 15 min before testing to measure potential residual effects of the previous treatment (none were noted).

The spray team consisted of a spray man and a timekeeper. The machines were started and throttled to operating speed; output was visually inspected to ensure that an aerosol cloud was being emitted. The generators were then held 1 m high and discharged for the appropriate time into the center of a domicile (Anonymous 1990). Four replications were conducted.

The Micro-Gen G3, London Fog Colt, London Fog Eliminator, and Clarke P1 produced droplets in an aerosol range (Anonymous 1985) (Table 1). This droplet analysis was conducted to ensure that all aerosol generators were functioning within a defined droplet range and, therefore, allowing easier comparisons. Aerosols are particles ranging in diameter from 0.1 to 50 μm with 80% of the particles having a diameter within a 0.1- to 30-μm range applied at 1.9 liter or less per acre with flow rates up to 532 ml/min (Anonymous 1985). Droplet parameters within the aerosol range are further specified for each insecticide labeled for ultra-low–volume dispersal. These devices offer a great deal of versatility and have been commercially available for some time for spot treatments and difficult to reach areas. However, note that all of these devices can be difficult to calibrate at low flow rate settings and considerable time must be devoted to working with them. Additional tests with different sized pressure relief orifices to control flow rates (at the P1 setting no. 2), indicated that a 3-mm orifice drilled in the nozzle fitting on the pressurization line leading to the insecticide tank allowed a lower flow rate of 2.6 ml/min (0.65 ml/15 sec) (Table 4). Droplet densities for the P1 ranged from 852 to 134/cm² as the sprayer was moved from 0 to 10.8 m, respectively. Droplet density for the Eliminator ranged from 858 to 21/cm² as the sprayer was moved from 0 to 10.8 m, respectively. The lowest flow rate of the Eliminator (22 ml/5 sec) and Colt (9 ml/5 sec) exceeded the lowest for the P1 (2.3 ml/5 sec). Therefore, the P1 was chosen to conduct additional tests (Table 2). The addition of an orifice into the insecticide line and subsequent tests indicated the range of spray-on time providing 90% or greater caged mosquito mortality lay between 15 and 30 sec at a flow rate setting 2 (Tables 2 and 3) in this particular array of domiciles. Lower P1 settings were more erratic for insecticide output.

The tests in which a P1 and Eliminator were used to spray into and between the 1st domiciles for each row of domiciles demonstrated that little mortality occurred beyond the row of domiciles (Table 4). The Eliminator elicited a slightly higher, but not statistically significant, mortality response as the spray cloud moved downwind through and around the domicile complex (Table 4). The mortality difference between the 2 generators was so small as to make conclusions concerning superior performance difficult.

In developed areas provided with roads, operational advantages and timesavings are easily demonstrated with wheeled equipment. For those situations not endowed with sufficient roadways, Self et al. (1976) believed that backpack mist blowers should be used in conjunction with vehicle-mounted equipment. Backpack mist blowers also are significantly less expensive than vehicle-mounted equipment and allow areas without roads to be treated. In like fashion, we think that handheld equipment may provide adequate treatment in remote areas, and this equipment has the added benefit of low cost. Handheld equipment is used in many mosquito control districts throughout the USA, where handheld machines have come into prominence for spot treatments adjacent to individual domiciles as opposed to treating a block of domiciles. An additional value of this work lies in demonstrating the small amount of resmethrin and short spray-times that can be used effectively. In these tests, spraying the 1st row of domiciles and then relying on wind drift to disperse the aerosol cloud downwind apparently gains no advantage. The aerosol cloud simply was not aspirated into the remaining buildings. This result dictated individual domicile treatment.

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