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Dispersal of Ultra Low Volume (ULV) Insecticides by Cold Aerosol and Thermal Fog Ground Application Equipment

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TECHNICAL GUIDE NO. 13

DISPERSAL OF ULTRA LOW VOLUME (ULV) INSECTICIDES BY COLD AEROSOL AND THERMAL FOG GROUND APPLICATION EQUIPMENT

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TGs are not policy documents; rather, they provide technical guidance for the use of the DoD pest management community and others. TGs are a contributing part of the overarching DoD approach to integrated pest management. Each TG should not be considered as stand-alone guidance and should not be construed or referenced as policy. DoD pest management policies may be found in DoD Directive 4715.1E, "Environment, Safety, and Occupational Health (ESOH)" DoD Instruction 4150.07, "DoD Pest Management Program," other DoD directives and instructions, and implementing component directives/instructions/regulations.

FOREWORD

This Technical Guide is designed to give specific information on DoD policy and current practices for ground application in outdoor situations. Aerial application policies and procedures are not considered, nor are indoor applications. Competency in performance of aerial application requires separate certification by DoD, or an appropriate state agency. Given the sensitivity of the subject, it is imperative that the activity considering outdoor ULV application take time to consider undesired side effects and the opinions of others in the pesticide use debate. As a weapon in the arsenal of integrated pest management, ULV application should be included in the context of reducing the risk of transmission of vector-borne disease through full implementation of as many techniques as are practical given the military, political, or social conditions existing in the area of operations. Protecting the health of service members, family members, and other civilians from excessive exposure to pesticides must be fully incorporated into the treatment plan.

As practices and pest management materiel change, information in this TG may need to be updated. Your constructive comments are most welcome and will be given full consideration in further revisions of this document. Comments should be sent to Armed Forces Pest Management Board, ATTN: Equipment Committee Ex-Officio, Forest Glen Section, Walter Reed Army Medical Center, Forest Glen Annex, Bldg. 172
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1. INTRODUCTION AND PURPOSE

a. Sustained disease vector and nuisance pest control for routine and contingency military operations requires continual modification and updating of techniques and equipment. Coupled with changing pesticide requirements due to resistance and/or environmental considerations, the military utilizes state-of-the-art techniques to ensure protection of its forces. The use of ultra-low volume (ULV) insecticides and employment of aerosol generating equipment is one example of the methods introduced since 1960 in an effort to improve flying insect control. Primary emphasis is placed on ground control techniques; however, aerial dispersal equipment may be used successfully for vector-borne disease outbreaks where access or terrain curtail the use of ground equipment and vector suppression is immediately required.

b. This guide provides information concerning ULV pesticides, ground dispersal techniques, equipment, operation and maintenance considerations, and methods for required equipment evaluation. Equipment and techniques utilized for indoor or aerial dispersal of ULV insecticides are not included. Please see Mount et al. (1996) for a review of aerial dispersal methods and insecticides.

2. DEFINITION OF AEROSOL AND ULV INSECTICIDE DISPERSAL

a. Aerosol sprays consist of particles ranging in diameter from 0.1 to 50 microns (micrometers = µm) with most of the particles between 0.1 and 30 microns. According to the U. S. Environmental Protection Agency (EPA 1998) ULV as used in common agricultural practice refers to a total volume of 0.5 gal or less per acre (1.89 L or less per hectare) broadcast. For the control of public health vectors and pests, formulations are dispersed in active ingredient concentrations of up to 96% at flow rates up to 20 fluid ounces per minute. It is critical that insecticides be delivered within certain droplet size range to be effective. The optimum droplet size for effective (≥90% mortality) mosquito control by space spraying via ground application equipment is 8–15 µm volume median diameter (see VMD section 4c1 below for details) (Mount 1998), while a slightly larger droplet size (5-25 µm VMD) is most effective when applied by aerial methods (Mount et al. 1996). For controlling larger flying insects such as filth flies or tsetse flies, VMDs closer to 30 µm are recommended (WHO 2003). Mosquito control efficacy declines rapidly either as the droplet size falls below 5 µm or it rises above 25 µm VMD. Generating the correct droplet size range is therefore paramount to successfully controlling flying insects. The volume of material applied per unit area is a second important parameter of concern of space sprays. Undiluted ULV application rates of different insecticides run from 0.15-4 fl. oz. per acre using cold foggers, whereas thermal foggers deliver in excess of 10 fl. oz/acre of diluted materials. With the appropriate insecticides, droplet sizes and application rates, cold aerosol generators and thermal foggers have effectively controlled mosquitoes for decades and are therefore very capable of delivering insecticides within the effective droplet ranges needed to control flying insects of public health importance.

b. The term “ULV” in this TG is used to indicate an insecticide aerosol applied by either cold or thermal fog application equipment and delivered within the defined parameters for effective flying insect control (i. e., VMD <25 µm and where 90% of the spray volume is < 50 µm in diameter). Cold-ULV, cold aerosol and ULV insecticides are therefore synonymous in this

TG, whereas thermal fog aerosol droplets are usually smaller and occur at higher density, but they still fall within these parameters.

3. ADVANTAGES AND DISADVANTAGES OF COLD AEROSOL AND THERMAL FOG APPLICATION METHODS

a. The table 1 based on information from the insectcop.net web site compares two types of ULV sprays.

Table 1. Comparison of cold aerosol and thermal fog application methods in different performance categories. (Adapted from https://insectcop.net/#thermal-vs-cold-foggers)

Thermal fog generators	Cold fog generators
Visibility	
Dense, visible fog, therefore perfect observation of fog distribution and fog drift	Fog is hardly visible, therefore observation of fog distribution and fog drift is difficult
Positive psychological effect on people (something is being done)	Less psychological effect (nothing can be seen)
People can escape direct contact with the fog cloud	People cannot easily avoid the fog cloud
Efficacy	
Higher density of droplets increases chances of impinging on flying insects	Lower number of droplets reduces chances of droplets impinging the flying insects.
Better dispersion in lighter winds	Poor dispersion in lighter winds
Smaller droplets move quickly with higher wins making it less suitable	Larger droplets more compatible with higher winds making them more suitable
Smaller droplets more likely to be affected by thermals and turbulence	Larger droplets less likely to be affected by thermals and turbulence
Hazard	
Lower concentration of active ingredient (less hazard)	Higher concentration of active ingredient (more hazard)
Possible traffic hazards through dense fog	No traffic hazards because fog cloud is nearly invisible
High noise level of the machines	Lower noise level
Mixing required	Most formulations come ready to use and no mixing
Fire risk due to high temperature and flame production	No fire risk
Acceptability	
Strong smell due to high temperature carriers	Little or no smell caused by carriers
Staining by oily carrier substances	Minimum oily residues
Difficulty to operate	Easy to operate
Cost	
Less initial cost	More initial cost
Higher cost of carrier substances	Little or no carrier substances resulting in lower cost
Handling of higher volumes	Lower volumes to handle

b. The advantages listed above also apply to contingency or emergency operations. Development of lightweight cold aerosol dispersal units using concentrated insecticide without additives has significantly reduced weight and space requirements for deployment blocks. An additional advantage of thermal fogging is that the spray cloud is clearly visible to the applicator, showing exactly where active ingredient is dispersed. Observations of air currents, inversions and penetrations into vegetation where vectors may be resting are therefore easier.

Efficacy comparisons reported for ULV vs. thermal fog sprayers vary widely depending on insecticide used, vector targeted and environmental conditions present at the time of the evaluation, thus the debate over which sprayer type is better continues. A recent study by Britch et al. (2010) reported results from a comparison of ULV and thermal fog applications using malathion against mosquitoes in temperate and desert environments and showed greater efficacy from the thermal fog application in both environments. Numerous other studies show one or the other method as superior, therefore many variables come into play to determine efficacy in each unique spray scenario.

4. DROPLET SIZE CONSIDERATIONS FOR AEROSOL APPLICATIONS

a. Because ULV methods employ a very small amount of insecticide, knowledge of environmental characteristics and their effects on airborne droplets of various sizes is paramount for effective and safe ULV dispersal.

b. Adherence to optimal droplet size is essential so that the appropriate amount of insecticide is available in the droplet. It is generally accepted by the mosquito control industry that optimum droplet size for mosquito control is in the range of 5-25 µm in diameter where 8 – 15 µm droplets are most effective. Insecticidal efficacy decreases rapidly for droplet sizes smaller than 5 and larger than 25 µm. Generating droplets larger than 25 microns results in droplets that fall to the ground quickly, reducing insect exposure time and increasing potential hazards to the environment or personnel and is therefore wasteful or at best inefficient for ground dispersal application. Furthermore, droplets exceeding sizes stated in label specifications are capable of causing damage to automobile finishes or other painted surfaces. On the other hand, smaller droplets are more susceptible to drift and droplets that are too small may not impinge on the flying insect to deliver a lethal dose.

c. Understanding Droplet Size Distributions for ULV Dispersal.

(1) The permissible droplet sizes in the form of $D_{V0.5}$ and $D_{V0.9}$ are provided on pesticide labels and must be followed. Understanding label specifications and droplet distribution in an aerosol cloud requires knowledge of the terms used to describe droplet size characteristics expressed in microns (µm). The $D_{V0.5}$ also called volume median diameter (VMD) and equivalent to mass median diameter (MMD) is defined as the droplet diameter such that 50% of the total volume (or mass) of the spray is contributed by droplets smaller than this size expressed in µm. Similarly $D_{V0.1}$ and $D_{V0.9}$ are the droplet diameters such that 10% and 90%, respectively, of the total volume of the spray is contributed by droplets smaller than these sizes expressed in µm. Some current ULV labels still use the term MMD, although most recent literature uses the term VMD or $D_{V0.5}$. These terms are synonymous and interchangeable.

(2) Droplet sizes should show a reasonable distribution around the VMD, and the parameter to indicate this distribution is called span, which is defined as the difference between $D_{V0.9}$ and

$D_{V0.1}$ normalized by $D_{V0.5}$ [($D_{V0.9}$ - $D_{V0.1}$)/$D_{V0.5}$]. The larger the span, the wider the spread of the droplet size distribution and the span < 2 is considered ideal (WHO 2003).

(3) Following limitations imposed on ULV spray under section 2b above, if a $D_{V0.5}$ is larger than 25 or if a $D_{V0.9}$ is larger than 50, some adjustment to the flow rate or other machine operating characteristics or necessary repairs will be required to establish the correct range. If a large number of droplets, five microns or less, are produced and they constitute a small percentage (less than 10%) of the volume (mass), the remaining droplets will normally produce effective control. However, the final guidance, and the law, is the insecticide label. Labels vary in their requirement of VMD and selected ones are listed below in Table 6 of section 10, ULV insecticides.

5. MEASUREMENT OF DROPLETS FOR ANALYSIS OF ULV PERFORMANCE

a. General Considerations. Droplet size determination is necessary at frequent intervals to determine particle size and confirm adherence to application requirements. This should be accomplished at the beginning of each spray season and for every 50-100 hours of operation thereafter. If a machine remains idle for a month or more, recalibration and droplet evaluation are advisable.

b. Specialized equipment and training of personnel are required to properly determine and evaluate droplet production. There are several methods currently used to determine droplet size.

c. Three popular for field use in mosquito control are: DC-4 (KLD Labs, Inc., Hauppauge, NY), Teflon® slides, and magnesium oxide (MgO) slides. The DC-4 is a hot-wire probe that is inserted into an aerosol cloud, and conductance change is measured when droplet impingement occurs. This measurement is converted to an MMD and displayed on the screen. The distance at which the probe must be held is dependent on the air blast from the sprayer and will differ from machine to machine. However, the probe must be held where the air velocity is 5-7 m/sec. Teflon® and MgO slides are used to characterize droplet size distribution of oil and water based products, respectively and can be employed to characterize a wide distribution of droplet sizes. Teflon® coated slides are available in 3 mm and 25 mm width. The slides are either waved through the spray cloud or rotated on slide impingers inside the spray cloud to collect droplets. The total volume of a droplet sample collected on a coated microscope slide (200 droplets on some labels) is calculated and divided into two equal volumes. The division line is the VMD. Now the DropVision system (Leading Edge Associates, Inc., Fletcher, NC) can also be used to measure droplets on slides. The associated software determines droplet size characteristics and expresses measurements in µm.

d. Laboratory measurements of droplets can be done using a Phase Doppler Particle Analyzer located at NECE or with a Sympatec laser located at Aerial Application Technology Research, USDA-ARS, College Station, TX. For droplet measurements, the spray equipment must be sent to one of these labs. Droplet size measurements for different settings of the sprayers can be done quickly and easily with these units.

e. With instructions provided in this TG, the operator can collect droplets from a machine and submit them to a laboratory for analysis. When a slide sample is analyzed, $D_{V0.5}$ and $D_{V0.9}$ of the spray provide enough information to determine if the equipment is operating properly. Contact the appropriate pest management professional for information concerning services that can assist in making droplet measurements. ***NOTE*: *see* <u>*Appendix E*</u> *for additional information, equipment and supplies needed, and specific guidelines for all aspects of procedures required.***

6. DISPERSAL METHODS AND EQUIPMENT

a. Basic Considerations. Effectiveness of ULV ground applications for adult flying insect control is dependent upon many factors such as the inherent toxicity of the insecticide, insecticide concentration and application rate, proper equipment calibration and operation, selection of appropriate equipment parameters, vehicle speed, activity of the target population, meteorological conditions, topography, vegetation height and density to name a few. Droplet size, droplet distribution and application rate have added significance because of the very small volume of insecticide applied to an area to achieve control. All these factors can be divided into four categories and are discussed below:

(1) Pesticide characteristics: These include physical properties as density, viscosity and surface tension of the formulation, concentration of active ingredient in the formulation, carrier fluid such as water or oil distillate, and application rate. The pesticide labels specify permissible droplet size in the form of $D_{v0.5}$, $D_{v0.9}$, maximum droplet size, minimum interval between subsequent applications, and maximum amount that can be applied to the same area during a time frame specified.

(2) Insect Behavior: These include time of flight or biting activity, preferred resting or hiding places, and height of general presence above ground.

(3) Atmospheric Conditions: These include wind speed, wind direction, relative humidity, ground temperature and air temperature. Some pesticide labels limit applications within a range of air temperature. ULV pesticides have a limit of wind speed of 1 -10 mph. Ground and air temperature as well as wind speed are combined to determine the stability of the atmosphere. When ground temperature is lower than air temperature, this condition is called inversion which is considered most suitable for ULV sprays. When ground temperature is about equal to air temperature, this is called neutral condition and is also suitable for ULV sprays. However, this condition is very short lived in nature. These two conditions occur after sunset and last until a few hours after sunrise. When ground temperature is higher than air temperature, thermals are created which lift spray above ground. This condition is called convective which occurs during day time and is not suitable for ULV sprays. However, research (Miller et al. 2012) has found that if the wind is > 6 mph, the wind suppresses the thermals and make the conditions suitable for ULV sprays. This means that under 6 – 10 mph winds, ULV sprays can be applied during day time.

(4). Equipment. Performance of ULV equipment changes with the changes in settings on the unit. These settings are flow rate, type of flow control, type of nozzle including method of droplet formation, air volume and velocity at the nozzle. All of these settings affect the spectrum of droplet sizes generated by the sprayer. Recently, the factors such as nozzle orientation and travel speed have been found to affect delivery and dispersion of generated droplets. It has been found that horizontal nozzle performs better than conventional 45 upward angle (Farooq et al. 2017). It has also been found that higher travel speed performs better (Farooq et al. 2018). It has also been found for spray to penetrate better in to dwellings when doors and windows are open during spray (Farooq et al 2018). For best performance, the settings on the ULV sprayer need to be selected to match the pesticide and insect characteristics and atmospheric conditions.

b. Other Factors: ULV ground equipment, whether produced for commercial or military use, must meet certain requirements. Components coming in contact with the insecticide merit special attention. These are: formulation tanks and its components, tubing carrying the insecticide from the tank to the atomizing head, flow control valves, pump assemblies, and exterior portions of the dispersal unit subject to liquid contamination. Equipment intended for use over rough terrain should be designed to withstand hard usage without breakdown. Electronic components should be heavy duty to withstand the effects of heat, solvents, and vibration. A review of ULV ground dispersal equipment indicates that many manufacturers use common components. Therefore, several generalizations concerning design (e.g. FMI pumps, Roots blowers) and operation may be made. All these characteristics are tested during evaluation of an application equipment before it is added to NSN list. However, it does not mean that only equipment in the NSN list meet these criterion.

c. Methods of Generating ULV Droplets.

(1) Air-shear nozzles or twin-fluid nozzles: In this type of nozzle, kinetic energy of the high speed air is transferred to liquid that breaks it in to droplets. These nozzles are also called as air-shear or air-blast nozzles. With twin-fluid nozzles, the liquid sheet or jet exposed to the atomizing air has little initial momentum and the droplets formed in atomization are entirely dependent on the kinetic energy of the atomizing air to transport them away from the nozzle. Thus, with this type of nozzle, the droplets are airborne at their inception, and their subsequent trajectories are dictated by the air movements created by various aerodynamic devices which are sometimes integrated into the nozzle configuration. Injection of liquid in to air stream is usually accomplished inside the nozzle body, it can be injected outside, such as at the exit. The air-shear nozzles operate at low pressures resulting in low wear rates for both nozzles and the pump. Also, air-shear nozzles have large openings which minimize plugging. Dispersal units are powered by electric or gasoline engines. These devices have the greatest versatility in the selection of air and liquid pressures or flow rates to facilitate liquid breakup and control particle size.

(2) Thermal Fogger (thermal methods). Two basic types of thermal foggers are manufactured: rotating disk and heat chamber (e.g., pulse jet). In the rotating disk type, insecticide is drawn between rotating disks, heated and shunted into the exhaust system. The insecticide-fuel oil mixture is vaporized at a relatively high temperature (generally $\geq 250^{o}$ F) in the exhaust port and forced into a relatively low atmospheric temperature where condensation (= fog) occurs. The heat chamber type also disperses an insecticide fuel oil mixture. However, a standard insecticide pump may be used to shunt the material into a “heating chamber” where vaporization occurs.

(3) Rotating sleeves (mechanical). Insecticide is introduced by gravity or under pressure into a rotating porous cylindrical sleeve, forcing the liquid through minute openings to produce atomization. Droplet size may be controlled by the porosity of the sleeve and by varying the insecticide pressure, flow rate and rotational speed of the atomizer. Breakup of the liquid may be

further enhanced by air delivered from a fan producing a shearing action on the droplets. These units are usually electrically powered by 12-volt storage battery systems; sleeves and pumps are driven by electric motors.

(4) Rotating discs (mechanical). Insecticide breakup is accomplished by introducing the liquid by gravity or pressure onto a motor-driven, cylindrically shaped disc rotated at high speed. The insecticide impinging on the disc is propelled outward to provide initial breakup. Shear produced by a motor-operated fan produces atomization. These devices may be hand-held or portable and are powered by batteries.

(5) Electrostatic: A basic requirement for atomizing any liquid is to make some area of its surface unstable. The surface will then rupture into ligaments, which subsequently disintegrate into droplets. In electrostatic atomization, the energy causing the surface to disrupt comes from the mutual repulsion of like charges that have accumulated on the surface. Usually, an electrical pressure is created that tends to expand the surface area. The pressure is opposed by surface tension forces, which tend to contract or minimize surface area. When the electrical pressure exceeds the surface tension forces, the surface becomes unstable and droplet formation begins. If the electrical pressure is maintained above the critical value consistent with the liquid flow rate, then atomization is continuous. Sometimes, the droplets are formed by the air shear and are charged by the use of electrical energy.

There are several brands/models available for each method described above. Generally, each equipment company develops its own proprietary nozzle design to ensure the company's uniqueness. There are many references comparing proprietary nozzles. The label requirement for droplet spectra, however, is what determines whether a nozzle meets standards.

7. EQUIPMENT FOR MILITARY USE

a. General Considerations. Since the initial acceptance of the ULV method for insect control, design and construction of commercial and military dispersal devices have been in states of constant change. The first generation of ULV dispersal units required application methods based on rather strict insecticide temperature conditions and vehicle speeds. Although it is beyond the scope of this guide to describe the history of ULV equipment development, it should be noted that the military has been instrumental in promoting significant improvements. Current military specifications reflect these developments for large engine-operated and hand-held equipment. Commercial competition and field requirements generated by civilian and military agencies have stimulated innovations in equipment design that have simplified control operations and allowed greater latitude in application methods independent of speed and temperature requirements.

b. Tables 2 and 3 at the end of this section summarize the equipment specifications used for cold aerosol and thermal fog applications (stock and non-stock). Appendix D includes summaries of current testing and evaluation results for cold aerosol and thermal fog application equipment using a variety of ULV insecticides that are oil-, diesel- and water-based.

c. Equipment for Contingency Operations. Adulticiding equipment for use by military units in contingency or combat operations requires unique features. Equipment must be simple to operate and maintain, lightweight and portable, generate low noise levels, utilize a variety of pesticide formulations, and atomize effectively. Battery/electric-powered units often fulfill these requirements and have been accepted by the mosquito control community in the last decade. Both hand-held and truck-mounted units are available. Consult the DoD Pest Management Material Other Than Pesticides list on the AFPMB website for further information and images of the below listed items.

d. Standard Stock ULV Generators.

(1) Dispensers procured for standard stock consumption are supplied as complete units with operating manuals and are ready for use. Spare parts kits are generally included with the sprayer, but may be procured by military or open purchase procedures if needed. Operating and maintenance procedures should be thoroughly studied before attempting operations. Units dependent on liquid temperature should be initially calibrated for the range of their expected use in five-degree increments, usually 60 to 100°F. To ensure maximum effectiveness, minimize paint damage, and to confirm that the unit meets criteria to be a ULV, droplet analysis should be done and validated prior to machine use as explained in section 5a.

(2) ***Vehicle-transported*** **electric, gasoline or diesel engine powered equipment**.

(a) *Fog Generator, Skid Mounted, gasoline engine (18 HP) driven,* ***Clarke Grizzly PDS*** (NSN 3740-00-375-9154). 53” long, 31” wide, 37” high, weight 456 lbs empty, flow rate 0 – 18 oz/min, positive displacement blower w/6 psi max pressure, 15 gallon polystyrene pesticide tank. View Product Image and Specifications.

(b) *Sprayer, Pesticide, Skid Mounted, diesel engine (8.5 HP) driven,* ***London Fog ULV XKD*** (NSN 3740- 01-525-7453). 38” long, 33” wide, 31” high, weight 280 lbs, Flow Rate 0 – 8 oz/min, 15 gallon tank. View Product Image and Specifications.

(c) *Aerosol Generator, Pesticide, Skid Mounted, gasoline engine (18 HP) driven,* ***Curtis Dyna Fog Model 62825-1 [MAXI-PRO 4]*** (NSN 3740-01-141-2557). 44” long, 33” wide, 32” high, weight 495 lbs, Flow rate: 0 – 20 oz/min, 15 gallon tank. View Product Image and Specifications

(d) *Sprayer, Pesticide, Skid Mounted, gasoline engine (7 HP) driven,* ***London Fog, M.A.G.*** (Medium Area Generator) (NSN 3740-01-548-9102). 28” long, 18” wide, 21” high, weight 113 lbs, Flow Rate 0 –6 oz/min, 2 gallon tank. View Product Image and Specifications.

(e) *Sprayer, Pesticide, Skid Mounted, 12V electric DC motor driven* ***Curtis Dyna Fog Dynajet L-30*** (NSN 01-495-0914). 44” long, 29” wide, 39” high, weight 105 lbs, includes spare parts kits and battery, Flow rate 0 – 14 oz/min, 15 gallon tank. View Product Image and Specifications.

(f) *Sprayer, Pesticide, Skid Mounted, gasoline engine (18 HP) driven* ***London Fogger 18-20*** (NSN 3740-01-643-8496). 37” long, 46” wide, 39” high, weight 445 lbs, Flow Rate 0 – 20 oz/min, 15 gallon tank. View Product Image and Specifications.

(g) *Fog Generator, Pesticide,gasoline engine (88 HP) driven* ***Curtis Dyna Fog Silver Cloud Thermal fogger*** *Model 2650* (NSN 3740-01-535-8884) with twin pulse engines. 68" long, 24" wide, 22" high, weight 141 lbs empty, Flow rate 0 – 40 GPH. Attachments are provided for connecting to a suitable drum such as a 55-gal (2001) drum, which is not provided. Remote Control box included. View Product Image and Specifications.

(3) ***Hand-held*** **Standard Stocked ULV Generators**

Several units have been accepted for use by the Services for contingency operations and are currently listed on some or all of the military services authorized materials allowance list. These are:

(a) *Fog Generator, Manually Carried, gasoline engine (30 HP) driven* ***Curtis Dyna Model 2610 Golden Eagle*** (NSN 3740-00-818-6648). ***Thermal fogger***, provides indoor/outdoor thermal fog for mosquito and fly control, 52" long, 9.5" wide, 14.5" high, weight 32 lbs., 1 gallon tank. Flow rate 0 – 5 GPH at 6 psi, adjustable shoulder strap included. View Product Image and Specifications.

(b) *Fogger, Hand Held, Gasoline Engine Driven,* ***IGEBA Model TF-34*** (NSN 3740-12-375-2077), ***Thermal fogger,*** 30.7" long, 10.6" wide, 13.3" high, weight 14.5 lbs. empty, 1.5 gallon tank, Flow rate: 0 – 6.6 GPH. View Product Image and Specifications.

(c) *Fogger, Hand Held, Gasoline Engine Driven,* ***ULV***, ***London Fog Colt4*** (NSN 3740-01-456-2622). PN# 8675, 14" long, 11" wide, 12" high, weight 19 lbs., 0.25 gallon tank, Flow rate: 0 – 4 oz/min. View Product Image and Specifications.

(4) **Backpack Dispersal Units**. Most of the currently manufactured backpacks can disperse liquid, dust and/or granular formulations with accessory attachments. ***NOTE****: liquid dispersal rates and droplet sizes exceed those needed for ULV insect control (Hoffman et al. 2007b), therefore these devices will provide only limited flying insect control and should therefore be used primarily for residual treatments*. One unit has been accepted for use by the military services for contingency operations and is currently authorized for use in the military services materials allowance list. This backpack sprayer is:

Sprayer-Duster, Pesticide, Backpack, gasoline engine (3.9 HP) driven ***STIHL Model SR450*** (NSN 3740-01-463-0147), includes granular spreader. ULV (Not true ULV) nozzle only if ordered with pressure pump kit. Discharges mist 43 ft vertical/48 ft horizontal Comes with field parts kit, 49" long, 18.9" wide, 25" high, weight 29 lbs empty, 3.5 gallon tank, flow rate 0 – 128 oz/min. View Product Image and Specifications

Table 2: Summary characteristics of ULV cold aerosol sprayers (Stock [*italicized*] and Non-Stock)

Sprayer	Power Source		Nozzle type	Air Flow rate, CFM	Liquid Flow rate, oz/min		Tank Capacity gal	Fuel Capacity gal	Dimensions inch			Weight lbs
	Type	Size, hp			Min	Max			L	W	H	
London Fog Hand-held Colt	Gasoline	?	Air shear		0	4	0.25	0.25	14	11	12	19
ADAPCO Guardian 55 ES	Gasoline	5.5	Air shear	4	1.3	6.9	2.5	1.0	35	16	17	85
ADAPCO Guardian 95 ES	Gasoline	9	Air shear	169	0	20	15	1.5	38	30	27	350
ADAPCO Guardian 190 ES	Gasoline	19	Air shear	350	0	20	15	8.30	45	37	30	510
B&G Phoenix Fogger 680 MD	Diesel	6.8	Air shear	220	1	18	15	1.25	40	34	33	605
Clark Grizzly	Gasoline	18	Air shear	350	0	18	15	9	53	31	37	475
CDF Dyna-Jet L-30	Electric	12V DC	Rotary	1350	0	20	15	NA	44	29	39	105
CDF Maxi-Pro 4	Gasoline	18	Air shear	400	0	20	15	1.8	44	37	32	495
CDF Minilite	2-Cycle gasoline	1.8	Air shear	95	0	17	1.25	0.26	15	15	28	29
Clarke Pro-Mist Dura	Electric	12V DC	Rotary		0	6	15	NA	40	28	30	140
IGEBA Nebulo	Electric	110 V	Air shear		0.2	7.6	1	NA	16	14	14	9
IGEBA U5M	Gasoline	3.5	Air shear		0	8.5	5.3	0.5	24	21	23	84
IGEBA U15 HD-M	Gasoline	13	Air shear		0	17	15.8	1.6	35	31	36	366
London Fog XKD	Diesel	8.5	Air shear		0	10	15	1.6	38	33	31	280
London Fog 9-10	Gasoline	9.5	Air shear	356	0	18	15	1.5	46	37	39	355
London Fog 18-20	Gasoline	18	Air shear	356	0	18	15	7.5	37	46	39	445
LF Medium Area Generator	Gasoline	6.0	Air shear		0	10	2	0.5	29	18	19	110
Longray LR-18	Gasoline	18	Air shear	188	0	34	16	8	48	42	43	419
Micron AU 9200	Gasoline	20	Air shear	295	0	34	13.2	4	57	26	51	529
Swingtec Fontan Mobilstar	Gasoline	16	Air shear	188	2.8	28	21	5.3	34	30	37	282

Table 3: Summary characteristics of thermal foggers (Stock and Non-Stock).

Sprayer	Power Source		Water-based Products	Fog rate 1000 CFM	Liquid Flow rate, oz/min		Tank Capacity gal	Fuel Capacity gal	Dimensions inch			Weight lbs
	Type	Size, hp			Min	Max			L	W	H	
Hand Held												
CDF Golden Eagle	Gasoline	30	No	57	0.0	19	1.1	0.25	52	10	26	19
CDF Trailblazer	Gasoline	24	Yes	31.7	0.0	11	1.0	0.21	29	10	18	25
IGEBA TF34	Gasoline	14	Yes	-	2.8	14	1.5	0.30	31	11	13	15
IGEBA TF35	Gasoline	25	Yes	-	0.0	23	1.5	0.30	54	11	13	18
Longray TS-75 L	Gasoline	25	Yes	-	4.5	45	1.3	0.40	51	12	14	29
Micron AR 9E	Gasoline	15	Yes	-	2.8	24	1.6	0.30	45	11	13	17
ST SN50	Gasoline	25	Yes	-	5.5	24	1.7	0.37	52	11	13	19
Truck Mounted												
CDF Silver Cloud	Gasoline	88	No	250	0.0	85	55.0*	6.00	68	24	22	106**
CDF Model 1200	Diesel	11	No	760	32.0	256	15.0	1.25	79	35	32	620
LF F500E	Gasoline	16	No	-	64.0	85	55.0***	1.50	33	30	24	220
Longray TS-95	Gasoline	50	Yes	-	0.0	56	15.9	1.30	79	24	29	104
ST SN101 M	Gasoline	57	Yes	-	18.0	68	18.0	1.50	70	25	13	88

*Attachments are provided to use the drum.
**Empty weight without drum.
***Optional Stainless Steel container.

8. Comparative Analysis of Truck Mounted ULV sprayers having NSNs

This section is dedicated to comparison of different sprayers from an operational stand point. The following sprayers are currently on National Stock List and are included in the analysis.

- London Fog 18-20 (NSN 3740-01-643-8496)
- London Fog XKD (NSN 3740-01-525-7453)
- London Fog MAG (NSN 3740-01-548-9102)
- Clarke Grizzly (NSN 3740-00-375-9154)
- Curtis Dyna Fog Maxi Pro 4 (NSN 3740-01-141-2557)
- Curtis Dyna Fog Dyna Jet L30 (NSN 3740-01-495-0914)

a. Comparison of Specifications**:** Table 4 summarizes specifications of all truck mounted sprayers on National Stock List. General characteristics of the sprayers in Table 4 are discussed below.

b. Operational Requirements: All sprayers need a truck or at-least a motorized cart to move them in the field during application.

c. Power Source and Capacity: Three of the sprayers use larger (18 hp) gasoline engines, one each uses medium sized (7 hp) gasoline and diesel engines, one uses a 12 V battery as the power source and can be connected to a vehicle's electrical system for continued use. Large engine units can run continuously for 6-7 hours while all others can run for 1-3 hours with a full fuel tank or fully charged battery.

d. Formulation Tank and Capacity: Most of the sprayers have large (15 gal) tanks or can be fitted with one. These machines can run for 8 hours at a flow rate of 4 fl oz/min. On the other hand, one of the sprayers (London Fog MAG) has a small formulation tank that can spray only for 60 – 80 minutes with one full tank.

e. Size: Grizzly, London Fog 18-20, and Maxi Pro 4 can be considered as large machines considering dimensions and weight but Maxi Pro falls off this list because of its limited range of flow rate as ULV. By size and performance, London Fog XKD can be classified as medium size sprayer while the remaining shown on Table 4 are considered small size sprayers.

f. Type of Spray Output: As defined earlier, pesticide application devices are considered as ultra-low volume (ULV) if the volume median diameter ($D_{V0.5}$) is < 25 µm and 90th volume percentile ($D_{V0.9}$) is < 50 µm. Clarke Grizzly and London Fog 18-20 produce ULV droplets over their available range of flow rate. All other sprayers produce ULV droplets for the partial range of their flow rates (Table 4). Considering the range of flow rates suitable for ULV space sprays, they can be grouped into three categories as follows:

- Large volume sprayers: Clarke Grizzly; London Fog 18-20
- Medium volume sprayers: London Fog model XKD
- Small volume sprayers: Curtis Dyna Fog models Maxi Pro 4; Dyna Jet L30; London Fog MAG

Table 4: Comparison of specifications of truck mounted sprayers on National Stock List.

Line #	**Parameter**	**Grizzly**	**London Fog 18-20**	**Maxi Pro 4**	**London Fog XKD**	**London Fog MAG**	**Dyna Jet L-30**
1	Format	Truck mounted	Truck Mounted	Truck Mounted	Truck Mounted	Truck Mounted	Truck Mounted
2	Power	18 hp	18 hp	18 hp	7 hp diesel	7.0	12 V
3	Airflow rate, CFM	350	356	400			1350
4	Formulation tank, gal	15	15	15	15	2	15
5	Flow rate, oz/min	0 - 18	0 - 20	0 - 20	0 - 10	0 - 6	2.5 - 14
6	Minutes to empty at 4 oz/min	480	480	480	480	64	480
7	Fuel tank, gal	10.25	6.5	1.8	3.0	1	NA[1]
8	Fuel Consumption, gal/hr		1.0	1.6	N/A	0.5	NA
9	Minutes to empty		390	67	N/A	120[2]	165 min
10	Flush tank, gal	1.0	0.4	1.0			1
11	Weight, lbs	475	445	495	271	110	105
12	Length, in	54	37	44	42	29	44
13	Width, in	42	46	33	34	18	29
14	Height, in	42	39	32	30	19	39
15	Type of output	ULV	ULV	ULV≤4 oz/min	ULV≤8 oz/min	ULV 1-6[3] oz/min	ULV Oil ≤4oz/min
Droplet Characteristics for Liquids							
16	**Water Flow rate**	4-18 oz/min	4-18 oz/min	4 oz/min	4-8 oz/min	4 oz/min	4 oz/min
18	$D_{V0.5}$, µm	19.3 – 28.6	14.6 – 19.2	20.0	9.3 – 17.1	25.6	27.9
19	$D_{V0.9}$, µm	34.5 – 53.2	24.8 – 33.9	34.2	22.1 – 47.5	60.6	40.0
20	**BVA oil Flow Rate**	4-18 oz/min	4-18 oz/min	4 oz/min	4-8 oz/min	4 oz/min	4 oz/min
21	$D_{V0.5}$, µm	10.6 – 21.8	6.3 – 14.6	15.3	6.5 – 13.8	14.7	25.7
22	$D_{V0.9}$, µm	24.7 – 45.3	16.0 – 26.6	29.3	16.8 – 35.3	32.3	41.2

[1] N/A=Data not available
[2] With deep cycle marine battery
[3] This is good for BVA. For water, ULV range is 1-2 fl oz/min.

g. Operational Parameters and Capacities

(1) The application rate of a pesticide dictates what travel speed and what flow rates can be used for a sprayer. The three parameters are related with each other in the form of the relationship below:

$$S = \frac{495 \times F}{W \times AR}$$

Where:

S = Travel speed, mph
F = Flow rate, fl oz/min
W = Swath width, ft
AR = Application rate, fl oz/acre

(2) The overall range of application rates for all mosquito adulticides on the National Stock List is 0.12 to 4.0 fl oz /acre. Adulticide labels recommend travel speeds between 5 – 20 mph for space spray applications with ground equipment. Using the suitable flow rates for ULV for each sprayer in Table 2 , it was determined that all sprayers could be operated at 5- 20 mph travel speed for various levels of application rates within the range of 0.12 – 4.0 fl oz/acre. For this range of travel speed and the suitable flow rates, the ranges of application rates possible with all the sprayers are plotted in Figure 1 along with their respective flow rates.

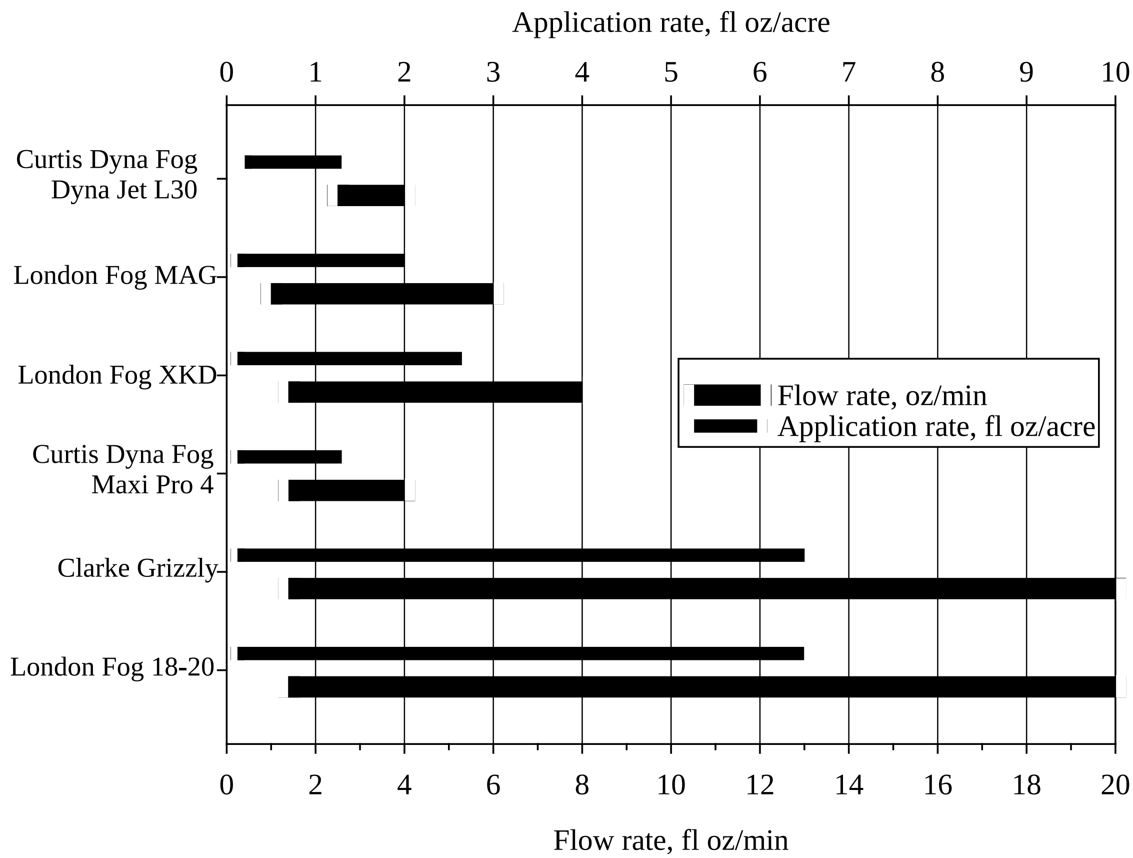

Figure 1: Ranges of flow rate and application rate for truck mounted sprayers with NSNs.

(3) The data in Figure 1 shows that only London Fog 18-20 and Clarke Grizzly, can be operated over the full range of required application rates. London Fog model XKD can be used for application rates of 0.12 – 2.65 fl oz/acre; London Fog MAG for application rates of 0.12 – 2.0 fl oz/acre; Curtis Dyna Fog Maxi Pro 4 for applications rates of 0.12 – 1.3 fl oz/acre; and Curtis Dyna Fog Dyna Jet L30 for application rates of 0.2 – 1.3 fl oz/acre.

(4) Work capacity of pesticide application equipment is another parameter that should be considered while selecting a sprayer. Figure 2 shows the acres covered by a sprayer in one hour for application rates of 1.3 fl oz/acre. This rate was chosen as it is the highest rate for some of the sprayers. Again, this data supports the classification of sprayers as large, medium, and small.

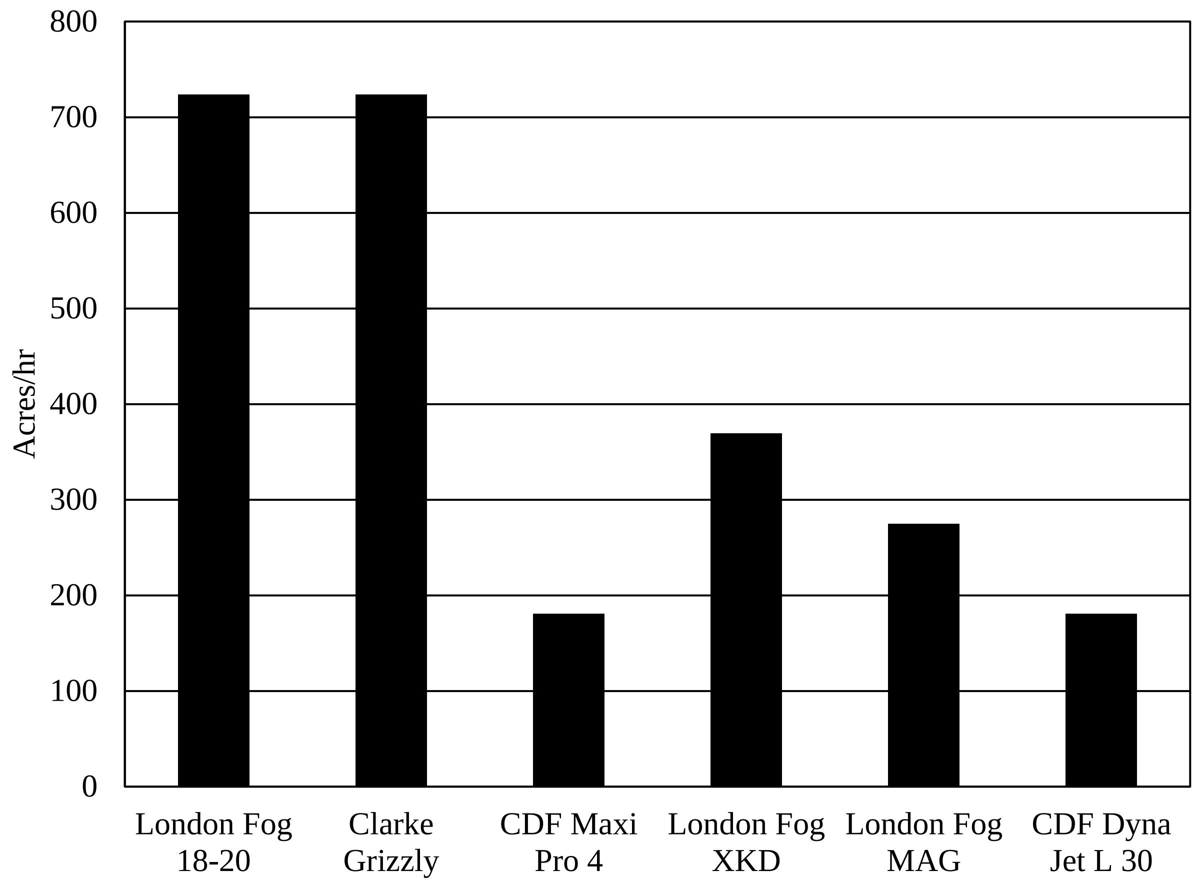

Figure 2: Work Capacity of truck mounted sprayers at 1.3 oz/acre.

h. Investment and Capacity Relationship

(1) The maximum area covered by an application in one trip of the spray equipment, such that the operator leaves the facility with full fuel and formulation in the tanks and continues to spray within the imposed limits. To estimate this area, the following limitations were selected:

- Work continues for 4 hours in a shift
- Fuel tank empties or battery discharges
- Formulation tank empties

(2) Based on these limitations, the area sprayed by each sprayer in a trip and the reason for termination is reported in Table 5. The table lists the price and investment per acre of each

unit if the unit is used for only one shift. With the assumption of running the machines for a full 4 hours per shift, the estimated investment per acre for each sprayer is listed in the last column of Table 5. Multiplying the number of shifts expected in a year for each machine provides a more realistic estimate of cost and investment per year. It should be noted that the investment for all sprayers except Curtis Dyna Fog Maxi Pro 4P can be improved by having extra pesticide formulation and fuel supplies in the truck and filling the tanks in the field without returning to the facility. The time required to fill the sprayers and the cost linked to it is not included in this estimation. These data show that London Fog MAG provides the best return on investment, followed by London Fog 18-20, and Grizzly. The most expensive unit is Maxi Pro 4.

(3) **Based on the analysis, conclusions drawn for the sprayers being considered in this guide are:**

- **The two large sprayers, the London Fog 18-20 and Clark Grizzly, compare to each other very well for capacity and cost. However, these sprayers are more suitable for applications >1500 acres/day.**
- **Among all small sprayers (applications <1000 acres/day), London Fog MAG is best for capacity and return on investment.**
- **Curtis Dyna Fog models Maxi Pro 4P and Dyna Jet L30 have similar work capacity and investment cost per acre.**
- **Dyna Jet L30 is not suitable at the lower end of application as the lowest flow rate with this can only be 2.5 fl oz/min.**
- **Maxi Pro 4P can be a good alternate among small sprayers as it can be used as a multipurpose sprayer including larviciding and barrier applications.**

Table 5: Estimate of area covered by each sprayer in one trip.

Sprayer	Area Sprayed		Reason for Termination	Price	Investment per acre for one day	
	Without refill	With Refill			One load	4 hr use
London Fog 18-20	1477	2895	Formulation used	$ 10550	$ 7.14	$ 3.64
Clarke Grizzly	1477	2895	Formulation used	$ 11670	$ 7.90	$ 4.03
Curtis Dyna Fog Maxi Pro 4	724	724	Four hours work	$ 10672	$ 14.74	$ 14.74
London Fog XKD	1181	1476	Fuel used	$ 9556	$ 8.09	$ 6.47
London Fog Mag	197	1100	Formulation used	$ 3990	$ 20.25	$ 3.63
Curtis Dyna Fog L30	498	724	Battery depleted	$ 10200	$ 20.48	$ 14.09

9. EQUIPMENT CALIBRATION.

a. Conducting aerosol applications for outdoor flying insect control requires specialized training by operators for the calibration, operation and maintenance of equipment to ensure compliance with label specifications, as well as to ensure proper droplet sizes are produced. Calibration of a machine should be made periodically, usually after 25 hours of operation, or any time when major maintenance is performed. Furthermore, if a change in insecticides is made, recalibration must be performed. None of the machines produced for commercial or military use have identical systems for control of liquid output. Follow the instructions provided with the equipment to determine flow rate. Although direct readout of flow may be indicated, its accuracy should be checked by the method in (b, c or d) above at some ambient temperature within the expected machine operating range.

Methods of calibrating flow rates for various kinds of ULV equipment are presented below, and Appendix C can be used to record equipment parameters.

b. Equipment with in-line flow meters and temperature gauges: In these cases flow rate calibration is relatively simple, requiring a stop watch and a graduated cylinder marked in tenths of an ounce or in cubic centimeters (milliliters). First, the machine is placed in operation; then, adjust the engine speed to establish proper insecticide tank pressure, and fill the insecticide lines. This may require letting some ‘‘run out’’ in order to fill the lines. Set the flow meter to an arbitrary setting (about mid-scale). Remove the discharge tube from the dispersal head, and hold it at the same level. Activate the control valve to start discharge. The insecticide is allowed to flow for one minute in to the cylinder, and the measurement is made directly in fluid ounces or milliliters per minute. For example, if the total amount of liquid discharged in this time is 128 ml, the flow rate is:

128 ml/min / 29.57 ml in 1 fl oz = 4.3 fl oz / min

If the total flow is higher or lower than the required rate at the existing temperature, flow rate or other parameters must be adjusted to establish proper application rate. Be sure to record the temperature at this setting, since the flow rate must be readjusted for any positive or negative change in temperature of 5 degrees or more.

If a machine is calibrated at a stated insecticide temperature, the machine should be used for operations under the same or nearly identical conditions, or the flow rate may differ greatly from that previously calibrated. Too little flow or output means poor control; too much output means waste, a possibility of paint damage or adverse effects on the environment. A calibrated graph should be plotted for high and low flow rates at temperatures between 60-100^{o} F.

c. Hand-held equipment may employ gravity feed systems using interchangeable orifices for establishing flow rate. For public health ULV operations, usually the smallest orifice provided will produce the desired flow. Although, flow rate for each orifice is provided in the manual, there is need to verify it at regular intervals as orifice may wear due to abrasiveness of the pesticides. For calibration of this type of sprayers and sprayers with fixed discharge tubes, use an accurate liquid level mark, run the sprayer to fill the lines and fill the tank to this level before a calibration run. Then run the machine for known time (1-5 minutes depending upon flow rate; more time for low flow rates and vice versa), measure the amount required to refill to the same level after the run. The boom and lines should be full before and after operation. For accurate measurement the sprayer should be in exactly the same position (preferably level) before and after operation. The volume required to refill and the time of run will determine the flow rate.

10. ULV INSECTICIDES

a. General Considerations.

(1) Although a number of insecticides are labeled for outdoor dispersal, relatively few are needed for military use. Currently available standard stock insecticides will satisfy most requirements. Occasionally non-standard pesticides may be needed to overcome a resistance problem, meet specific legal requirements or satisfy environmental constraints. Also, where the odor of the pesticide is offensive and cannot be tolerated, substitution may be desirable.

(2) Operational application factors must also be considered, and all are equally important. These are: (1) application rate required, (2) swath width, (3) flow rate, (4) vehicle speed, and (5) particle size produced by the machine.

b. Standard Stock Insecticides for ULV Ground Dispersal.

(1) *Malathion* (NSN 6840-00-655-9222 - 57%, 1gal can; NSN 6840-00-685-5438 -57%, 5 gal can): *Fyfanon* (NSN 6840-00-926-1481 - 96.5%, 54 gal drum; NSN 6840-01-169-1842 - 96.5%, 5 gal can). This is the most commonly used organophosphate in the United States for ULV ground dispersal. Advantages include demonstrated effectiveness against many pest and vector species and its relatively low mammalian toxicity. However, when applied in droplets much larger than those specified in the label, this compound has the ability to damage acrylic-based automobile paints. Machine adjustment must therefore be exact, and application rates followed carefully. Read the Label for specific speeds and rates of application allowed. Links for Malathion: MSDS. Label; Fyfanon: MSDS. Label.

(2) *Permethrin (Kontrol 4-4) with piperonyl butoxide 4.6+4.6%*, 2.5 gal container, (NSN 6840-01-550-5660). This pesticide can be applied as a ULV or as a thermal fog. However, this pesticide is extremely toxic to aquatic organisms. Machine adjustment must therefore be exact, and application rates followed carefully. Read the Label for specific speeds and rates of application allowed. Links: MSDS. Label.

(3) *Pyrethrins, 3% pyrethrins with synergists (ULV fog concentrate)*, 1 gal bottle, (NSN 6840-01-104-0780). This insecticide is most commonly used in hand held ULV machines and be applied at full strength or diluted using white mineral oil. Read the Label for specific speeds and rates of application allowed. Links: MSDS. Label.

(4) *Resmethrin (Scourge) 4% with piperonyl butoxide 12.4%*, 5 gal can (ready to use), (NSN 6840-01-359-8533). This insecticide is a **Restricted Use Pesticide** and must be applied by a certified applicator. The desired application rate may be obtained under different conditions by changing the flow rate and vehicle speed. Read the Label for specific speeds and rates of application allowed. Links: MSDS. Label.

(5) *Sumithrin 10% with Piperonyl Butoxide 10%, (Anvil 10+10 ULV),* 2.5 gal container, (NSN 6840-01-474-7751), and 250 gal container (NSN 6840-01-474-7706). Caution should be used when applying this insecticide as it is toxic to fish and bees**.** The desired application rate may be obtained under different conditions by changing the flow rate and vehicle speed. Read the Label for specific speeds and rates of application allowed. Links: MSDS. Label.

(6) *Etofenprox 20% (Zenivex E20),* 2.5 gal container, (NSN 6840-01-573-4964). This insecticide contains etofenprox, a close relative of pyrethroids. Read the Label for specific speeds and rates of application allowed. Links: MSDS. Label.

(7) *Permethrin 20.6 % with Piperonyl Butoxide 20.6%, (Aqualuer 20-20),* 2.5 gal container, (NSN 6840-01-606-8581). It can be used for ULV, Thermal and Barrier Applications using Ground and Aerial Equipment for control of Adult Mosquitoes and other biting flies. This product is extremely toxic to aquatic organisms, including fish and invertebrates. It is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Read the Label for specific speeds and rates of application allowed. Links: SDS. Label.

(8) For Aerial Application, Naled (Dibrom 87.4%) (NSN 6840-01-270-9765), (*Trumpet EC 78%*) (NSN 6840-01-532-5414). These two insecticides are extremely corrosive and require application equipment to be corrosion-resistant. These insecticides are standard pesticides used by the AF Aerial Flight Squadron. Links: MSDS. Label.

c. Non-standard Pesticides for ULV Dispersal. Several pyrethroid compounds with synergists are available with approval by major command professionals.

d. Droplet parameters within the aerosol range are specified on the label for each insecticide used for ULV-aerosol dispersal. Table 6 summarizes the label specifications for ULV insecticides used for mosquito control where mandatory droplet sizes are less than 50 micron for 90% of the spray volume.

e. *Label Specifications for Common ULV Insecticides*.

(1) There are certain standards set by federal and state agencies and chemical companies for the performance of a machine and a given pesticide. These standards, as part of the label specifications, must be met so that effective control can be achieved and hazards to personnel and property minimized.

(2) Portions of label specifications for the commonly used standard stock pesticides are quoted below as general guidelines. Before attempting operations or droplet assessment, read the complete label to ensure best results.

(3) *Fyfanon ULV*

(a) 50% of the total spray mass must consist of droplets smaller than 30 micron and 90 % of the mass must consist of droplets smaller than 50 microns.

(b) When Fyfanon droplets are collected on silicone coated slides, the spread factor, if not actually computed for an individual slide, is 0.5.

(c) Sampling distance should be 25 feet from the point of discharge.

(d) Silicone- or Teflon-coated slides may be used for sampling.

(4) *Kontrol 4-4 Formulations*.

(a) Droplets should be produced with VMD < 30 microns.

(b) The volume median diameter produced should be less than 30 microns.

(c) Sampling distance as per ULV machine manufacturer manual.

(d) Silicone coated slides may be used but Teflon® is preferable.

(5) *Anvil 10+10 Formulations*.

(a) Volume median diameter of the droplets produced must be < 30 microns and 90% of the spray mass must be no larger than 50 microns.

(b) Sampling distance as per ULV machine manufacturer manual.

(c) Silicone-coated slides may be used but Teflon is preferable.

(6) *Resmethrin (Scourge).*

(a) For ground equipment application the volume median diameter of the droplets produced must be adjusted to be < 30 microns and 90% of the spray mass no larger than 50 microns.

(7) *Aqualuer (permethrin)*

(a) VMD should be < 30 micron and 90% of the mass in droplets < 50 microns.

(b) Do not retreat same site more than once in three days and do not exceed 25 applications of maximum rate in a year.

Table 6. Summary of ULV Insecticides (Stock (*Italic*) and Non-Stock)

Insecticide	Active Ingredient		AI (lbs/gal)	ULV	Thermal Fog	Droplet size Range, µm	VMD µm	Diluted or undiluted	Dose Rate		Wind Range, mph
	Name	%							Formulation, Fl Oz/acre	Active Ingredient, lbs/acre	
Fyfanon ULV Mosquito	Malathion	96.5	9.9	Yes	Yes	90 % < 32	<17	Both	0.33 – 4.0	0.0255 – 0.3094	
Dibrom Concentrate	Naled	87.4		Yes	Yes			Both	0.1 – 0.2	0.01 – 0.02	
Trumpet EC	Naled	78		Yes	No	11-20	<15	UD	0.25	0.02	
Kontrol 4 4	Permethrin	4.6	0.3344	Yes	Yes	90 % < 48	<30	Both	0.67 – 2.67	0.00175 – 0.007	1 – 10
	Piperonyl Butoxide	4.6	0.3344								
Scourge	Resmethrin	4.14	0.3	Yes	No	90 % < 50	<30	Both	0.5 – 3.0	0.00117 – 0.0070	> 1
	Piperonyl Butoxide	12.42	0.9							0.00351 – 0.0210	
Prentox® Pyronyl™ Oil OR 3610-A	Pyrethrins	3		Yes	No			Both	1.32 – 1.65	0.00210 – 0.0027	5
	Piperonyl Butoxide	6								0.0043 – 0.0054	
	N-octyl bicycloheptene dicarboximide	10								0.0071 – 0.0089	
ULD BP-300	Pyrethrins	3		Yes	Yes			D	4.0	0.0064	
	Piperonyl Butoxide	6								0.0129	
	N-octyl bicycloheptene dicarboximide	10								0.0216	
Anvil 10 + 10 ULV	Sumithrin	10	0.74	Yes	Yes	90 % < 50	< 30	Both	0.21 – 0.62	0.0012 – 0.0036	> 1
	Piperonyl Butoxide	10	0.74							0.0012 – 0.0036	
Zenivex E20	Etofenprox	20	1.48	Yes	Yes	90 % < 50	10 – 30	Both	0.15 – 0.59	0.00175 – 0.007	1 – 10
Anvil 2 + 2 ULV	Sumithrin	2	0.14	Yes	Yes	90 % < 50	8 – 30	UD	1.08 – 3.25	0.0012 – 0.0036	>1
	Piperonyl Butoxide	2	0.14							0.0012 – 0.0036	
Acquahalt	Pyrethrins	5		Yes	No	90 % < 50	< 30	UD	0.28 – 0.76	0.0009 – 0.0025	
	Piperonyl Butoxide	25								0.0045 – 0.0125	
AcquaAnvil	Sumithrin	10	0.847	Yes	No	90 % < 50	8 – 30	Both	0.18 – 0.54	0.0012 – 0.0036	
	Piperonyl Butoxide	10	0.847							0.0012 – 0.0036	
Biomist 4 + 4 ULV	Permithrin	4	0.3	Yes	Yes	90 % < 50	8 – 30	UD	0.75 – 3.0	0.00175 – 0.0070	
	Piperonyl Butoxide	4	0.3							0.00175 – 0.0070	
Duet	Prallethrin	1	0.085	Yes	No	90 % < 50	8 – 30	Both	0.41 – 1.24	0.00030 – 0.0008	
	Sumithrin	5	0.37							0.0012 – 0.0036	
	Piperonyl Butoxide	5	0.37							0.0012 – 0.0036	
Flint 10EC	Permithrin	10		Yes	No			D	0.29 – 1.16	0.0016 – 0.0064	
ULV Mosquito Master 412	Chlorpyrifos	12	0.9	Yes	No	90 % < 50	8 – 30	UD	0.74 – 1.42	0.0050 – 0.0100	> 1
	Permithrin	4	0.3							0.0017 – 0.0030	
Mosquitomist One ULV	Chlorpyrifos	13.6	1	Yes	Yes	90 % < 50	8 – 30	Both	0.64 – 3.70	0.0050 – 0.0289	

11. APPLICATION PARAMETERS FOR ULV INSECTICIDES

a. **General Considerations**. Any computation of dispersal unit flow rate is based upon the speed at which it moves, application rate, and insecticide concentration. Depth of treatment (swath width) and travel speed must be established to enable computation of the flow rate. Dosage or application rate is dictated by labels in either fluid ounces or pounds of technical concentrate (actual) per acre. In reality what is being treated is a volume of air above the surface of the earth, called the “space” or "insect zone".

b. **Swath Width**. Perhaps no other single factor in the computation of dosage rate receives so much discussion as the meaning of the term "swath" or "effective swath width." Many arbitrary definitions have been given to this term. The recommendations of the manufacturer or governmental research activities will be acceptable as guidelines. In practice, the operator is governed by the actual area being treated. In addition, applicators may not be able to apply insecticide in the exact manner recommended due to the physical layout or geography of the area. As long as the insecticide is dispersed evenly at recommended dosage rates in more or less equal swaths across the area to be treated, the control procedure will be effective. According to published information, the swath width determined for ULV applications is 300 ft, which is adequate for all but the most densely vegetated areas. Historically, this 300 ft interval came from the center of one road to the center of the next road, demarcating a city block. In early tests, treatment of that area with insecticide resulted in 80% mosquito mortality. Effective control was set at or above 90% in the extensive review by Mount (1998). Effective swath width is the distance at which "effective" control is obtained. Generally, an effective swath width is determined by experimentation and is accomplished by one of two methods: direct evaluation of kill of exposed caged insects, or reduction in landing rate on humans where a natural vector population occurs. Swath width is generally included on the insecticide label. If not, then tests should be conducted to determine the distance at which 90% control is achieved. These tests are highly variable in nature, requiring sufficient replications to achieve an acceptable statistical level, and may require more time than the average mosquito control district or military operations spray team may have.

The Major Command Pest Management Consultant/Entomologist and distributor/formulator should be able to address questions concerning swath width. Once the swath width has been established and a firm recommendation has been made by a company or agency, the operator should make every effort to adhere to the recommendation for swath spacing, vehicle speed, and output to accomplish effective control.

c. **Application Rate**.

(1) General Considerations: Each insecticide has different physical and chemical properties, and biological effectiveness. Therefore, different dosage rates must be established for specific control situations or species involved. The labels generally give a range of application rates or a table of rates with different rates for various scenarios (see Table 6). It is generally given as the weight of active ingredient per unit volume of formulated insecticide. The pest management professional or applicator need to decide what application rate would be appropriate for the specific

treatment. The volume of formulated pesticide is also given on the label. If it is not, it can be calculated from the concentration of active ingredient in the formulation (lbs/gal).

(2) **Application Rate Calculations**.

For most truck mounted ULV applications, the effective swath is 300 ft while for hand carried applications, it is 50 ft and practical vehicle speeds are usually set at 5 - 10 mph.

d. **Formulation Application Rate (fluid oz/acre),** if not given on the label **=** *Active ingredient rate (lbs/acre) x 128 ÷ Concentration of Active Ingredient in Formulation (lbs/gal).*

e. **Flow Rate (fluid oz/min)** = *Vehicle Speed (mph) x Effective Swath (ft) x Application Rate (fluid oz/acre) ÷ 495*

or, if the Application Rate is in gal/acre or L/acre, the flow rate will be in gal/min or L/min, respectively.

Example Using Fyfanon:

The label gives flow rate in fluid oz/min for vehicle speeds of 5, 10, 15, and 20 mph. These flow rates are given for a swath of 300 ft. For non-agricultural lands, it gives a range of application rates from 1-3 fluid oz/acre. The above equation will help to find the flow rate.

Flow rate = 10 mph x 300 ft. swath x 2 fl. oz/acre ÷ 495 conversion factor = 12.12 fl. oz/min.

For an application scenario, it might not be possible to set the required flow rate (due to machine limitations), vehicle speed or swath width. In these cases, pick the two parameters that you can control and calculate the third parameter accordingly:

f. **Vehicle speed and swath width fixed use above equation for flow rate**

g. **Vehicle speed and flow rate fixed:**

Swath width (ft) = *[495 x Flow rate (fluid oz/min)] ÷ [Vehicle Speed (mph) x Application rate (fluid oz/acre)]*

h. ***Swath width and Flow rate fixed:***

Vehicle Speed (mph) = *[495 x Flow rate (fluid oz/min)] ÷ [Swath width (ft) x Application rate (fluid oz/acre)]*

i. Determination of acres sprayed/hour: It has been established that the effective swath for truck mounted ULV Fyfanon applications is 300 ft, and practical vehicle speeds are from 5 or 20 mph. Therefore:

Acres covered per hour = *Vehicle speed (mph) x 5280 (ft. in 1 mile) x swath in feet/43,560 (sq. ft in 1 acre)*

For 5 mph, rate = 5 x 5280 x 300/43560 = 181.8 acres/hour.

For 20 mph, this figure would be quadrupled to 727.2 acres/hour.

The established flow rate for 5 mph is a maximum of 2.1 fluid ounces per minute or for one hour is 60 x 2.1 = 126 fluid ounces per hour. Therefore 126/181.8 = 0.6931 fluid oz/ac.

The stated weight of technical malathion in Fyfanon is 9.9 pounds per gallon. One fl oz will weigh: 9.9/128 (fl oz in gal) = 0.077 pounds per fluid ounce. Therefore, the deposit rate per acre is 0.077 x 0.6931 or 0.054 lbs/ac deposit of technical (actual) malathion. For 20 mph, and a maximum flow rate of 8.6 fl oz/min, the application rate is:

(60 x 8.6)/727.2 = 0.71 fluid ounces per acre, or a deposit of 0.077 x 0.71 = 0.055 pounds per acre deposit of technical malathion.

j. Simpler procedures can be used to estimate the same figures as above. An effective method of determining the acreage covered per minute is:

Speed (mph) x swath (ft.) / 500 = acres covered per minute

For example, a speed of 5 mph with a 300 foot swath gives 5 x 300 / 500 = 3 acres per minute. For a maximum flow rate of 2.1 fl oz/min, the deposit rate per acre is 2.1 / 3 = 0.7 fl oz/ac, or a deposit of 0.077 x 0.7 = 0.054 lbs/ac deposit of technical malathion. The deposit rate for a 10 mph speed is 10 x 300 / 500 = 6 acres per minute when the flow rate is doubled, and deposition rate is the same 0.054 lb/acre.

12. PRACTICAL CONSIDERATIONS FOR ULV OPERATIONS (Also see section 6a)

a. Although most mosquito populations can be effectively managed by ULV insecticide application, exceptions occur. The target species' biology and flight habits, climatic conditions and the physical environment that affect aerosol cloud dynamics, and other variables combine in complex ways to determine final insecticide efficacy. Some mosquito species have particular activity patterns unique to them. Therefore, using space sprays to control them must occur not only at the right place but at the right time. ***It is crucial to review the biology and activity patterns for each species targeted to determine the best time and place to conduct space spray operations***.

b. Application timing: Schmidt (2003) summarized periods of peak activities for eight common mosquitoes in New Jersey. With this kind of information, we can determine the best time for fogging operations. For example, in New Jersey, *Oc. trivittatus, Oc. canadensis* and *Oc. sollicitans* should be sprayed 30 minutes *before* sunset, *Culex spp.* and *Coquilettidia perturbans* should be sprayed 30 minutes *after* sunset, and sprays to target *Ae. vexans* and *Ochlerotatus cantator* should be made *exactly at sunset* to achieve the best control.

Atmospheric stability also affects time of application for ULV sprays. It is an indication of difference in ground and air temperature. When ground is hotter than the air above it, the conditions are called unstable or convective. When ground is cooler than the air above it, it is called stable or inversion condition. When the two are at similar temperature, the conditions are called neutral. Atmospheric stability transition from unstable to neutral to stable and vice versa as day transitions between day and night. On a clear day, it is mostly unstable during day and stable during night. ULV spray is recommended to be applied during neutral or stable (inversion) conditions. However, as study (Miller et al. 2012) has shown that if wind speed is more than 6 mph, it can be applied during day time.

c. Urban physical factors affecting application efficacy. Different species may occur in habitats that negatively affect aerosol dynamics and hinder aerosol clouds from reaching the target. In controlling *Aedes aegypti*, for example, the adult mosquito rests in heavily sheltered sites indoors when not feeding or ovipositing (Reiter 1993). Targeting the mosquito in such indoor locations is largely ineffective using aerial or vehicle-mounted fogging methods because the spray cloud may be physically blocked by windows, vegetation, brick walls and the houses themselves that cause convection currents that interfere with spray cloud dispersion and penetration. Such conditions hamper effective control methods and therefore require additional efforts. Therefore, for controlling urban day-biting vectors like *Ae. aegypti* and *Ae. albopictus*, aerosol applications via vehicle-mounted equipment as well as house-to house indoor applications using hand-held fogging equipment should be made for the best chances of control (Matthews 1996; Mani et al. 2005; Perich et al. 1990, 1992; Reiter, 1993). The use of maximum label rates are also likely necessary to compensate for factors that make control in such urban environments extremely difficult. For new ways to make penetration easier, please check section 6a(4).

d. Terrain and vegetation type will greatly influence the requirements for droplet size and the ultimate effectiveness of an application. In open terrain with relatively sparse vegetation, greater effective swaths can be obtained. As vegetation density increases, less insecticide penetration occurs. This 'insecticide penetration' factor must be considered for each environment.

e. Wind speed has a profound influence on particle distribution and impingement. For most operations, wind speeds from 1 to 10 miles per hour (mph) will produce the best results. However, data indicate that wind speeds in excess of 10 mph may markedly increase penetration of insecticide into vegetation. Observations of the spray cloud must be made to determine if air flow is carrying the spray cloud into, over, or around the desired target vegetation.

f. Additional Practical Information

The following references/links provide additional information to consider when thermal fog and cold aerosol application methods are to be used to control public health pests.

(1) The World Health Organization's publication entitled "Space spray application of insecticides for vector and public health pest control" (WHO 2003) was co-authored by the Navy Entomology Center in Jacksonville where extensive equipment testing and evaluation is regularly

performed. This document and TG 13 complement each other very well to provide excellent references for space spray operations. The link to this document is provided here:

(2) William F. Lyon and J. A. Steele. 1998. Mosquito Pest Management, Bulletin 641. The Ohio State University.

(3) The following abstract is reproduced from Mount (1998) and provides very good information on ground ULV application methods and equipment (not otherwise available without internet access).

This review of ultralow-volume (ULV) ground aerosols for adult mosquito control includes discussion on application volume, aerosol generators, droplet size, meteorology, swath, dispersal speed, assay methods, insecticide efficacy, and non-target effects. It summarizes the efficacy of ULV insecticidal aerosols against many important pest and disease-bearing species of mosquitoes in a wide range of locations and habitats in the United States and in some countries of Asia and the Americas. Fourteen conclusions were drawn from the review. 1) ULV ground aerosol applications of insecticide are as efficacious against adult mosquitoes as high- or low-volume aerosols. 2) ULV aerosols with an optimum droplet size spectrum can be produced by several types of nozzles including vortex, pneumatic, and rotary. Droplet size of a particular insecticide formulation is dependent primarily on nozzle air pressure or rotation speed and secondarily on insecticide flow rate. 3) Label flow rates of insecticide for ULV aerosol application can be delivered accurately during routine operations with speed-correlated metering systems within a calibrated speed range, usually not exceeding 20 mph. 4) The most economical and convenient method of droplet size determination for ULV aerosols of insecticide is the waved-slide technique. (*Update: There are convenient methods available now – see section 5d*). 5) The efficacy of ULV ground aerosols against adult mosquitoes is related to droplet size because it governs air transport and impingement. The optimum droplet size for mosquito adulticiding is 8-15 microns volume median diameter (VMD) on the basis of laboratory wind-tunnel tests and field research with caged mosquitoes. 6) In general, ULV aerosols should be applied following sunset when mosquitoes are active and meteorological conditions are favorable for achieving maximum levels of control. Application can be made during daytime hours when conditions permit (*Wind speeds > 6 mph*), but rates may have to be increased. The critical meteorological factors are wind speed, wind direction, temperature, atmospheric stability and turbulence. 7) Maximum effective swaths are obtained with aerosols in the optimum VMD range during favorable meteorological conditions in open to moderately open terrain. The insecticide dosage must be increased in proportion to increased swath to maintain the same level of mosquito control. 8) Dispersal speed within a range of 2.5-20 mph is not a factor affecting efficacy if insecticide rate and optimum droplet size are maintained (*Update: New data shows increased efficacy with increased wind speed*). 9) The results of caged mosquito assays are comparable with reductions in free-flying natural populations. 10) The field efficacies of mosquito adulticides applied as ULV ground aerosols are predictable from the results of laboratory wind-tunnel tests. 11) Results of field tests in open to moderately open terrain during favorable meteorological conditions indicated that ULV insecticidal aerosol application rates producing 90% or more control of *Anopheles*, *Culex*, and *Psorophora* spp. are below or approximately equal to maximum United States Environmental Protection Agency label rates. Against some Aedes spp., some pyrethroid insecticides must be synergized to produce 90% control at label rates. 12) Results of field tests in residential areas with moderate to dense vegetation and in citrus groves or other densely wooded areas showed that insecticide rates of ULV ground aerosols must be increased 2-3-fold to obtain 90% or more control of adult mosquitoes. However, the maximum rates on some insecticide labels would have to be increased to allow higher application rates. 13) Applications of ULV ground aerosols of insecticide in accordance with label directions following sunset do not pose a serious threat to humans, non-target beneficial animals, or automotive paints. 14) Some aerosol generators operated at high RPM levels exceed the OSHA 8-h hearing hazard criteria of 90 dBA and may require hearing protectors for operators.

The tables 6-10 in Mount (1998) provide valuable information on insecticide flow rates, application rates and vehicle speeds for the effective control of mosquitoes under normal conditions.

13. EQUIPMENT MAINTENANCE AND REPAIR

a. General Considerations: Equipment maintenance and repair are among the most frequently neglected activities in control programs. Many equipment operators understand little beyond the procedures necessary to start and stop the machine or adjust the flow rate as required, and they perform only the essential cleaning functions necessary to ready the machine for use in the next operation. Thus, most of the blame must rest with the operator himself if a machine fails and is unavailable when needed because some routine, but essential, repair or maintenance procedures were not followed. Administrative difficulties often occur, such as responsibility for operation being assigned to one department, and repair to another. Most of the equipment are completely foreign even to experienced maintenance or automotive mechanics; therefore, repair is delayed or performed poorly. When a self-reliant operator learns to maintain and repair his equipment properly, he may not have the opportunity to adequately train his replacement, and the process repeats itself. There is no certain solution to this problem, but conditions could be improved if command personnel were to insist upon training specially designated personnel in the procedures necessary to keep equipment operating with a minimum of "down time."

b. Equipment Maintenance Procedures: Because the design and configuration of ULV equipment varies so widely, specific information concerning each unit approved for military use is beyond the scope of this guide. The following are generalized procedures applicable to all ULV dispersal units:

(1) When a new machine is procured, make copies of the operating and maintenance manuals, and keep one with the machine.
(2) Follow operating procedures carefully as outlined in the manual such as checking fluid levels.
(3) Operators should be capable of performing maintenance on all portions of the machine except the engine and compressor systems.
(4) Operators should be capable of changing oil, fuel and air filters on the engine.
(5) Equipment cleanliness, both internally and externally, is the most vital consideration. Thorough machine cleaning with a solvent is absolutely essential after each operation to maintain equipment in peak operating condition. Pesticides and their solvents can cause irreversible damage to critical parts, especially equipment seals, gaskets and electrical wiring. Consult the manual for specific guidance on solvent to be used. Isopropyl alcohol

or other acceptable solvents such as Mineral Oil, Light NF (NSN 6505-00-664-0441) or Marvel Mystery Oil (NSN 9150-01-126-4459) should be used to clean insecticide lines each time the machine is secured from operations. If insecticide is spilled on external portions of the machine, cleaning should be accomplished immediately. Some solvents may be harmful to equipment components. Acetone, for example, may damage seals or gaskets used in solenoid valves.

(6) Use a strainer for pesticide filling operations. Foreign matter in pesticides will significantly increase maintenance problems.

(7) Engine and compressor maintenance schedules, whether from the manufacturer or military command, should be carefully followed to ensure long machine life and proper performance.

(8) Spare parts for equipment should be procured when the machine is new to ensure their availability. For contingency operations, spares of the components most subject to failure may be desirable where resupply is difficult.

(9) The electronic controls and circuitry for aerosol equipment are not complex, and it should not be difficult for a capable technician to determine malfunctions. However, to simplify field repairs, replace the complete circuit board.

c. Routine Maintenance Items.

(1) Grease gun with lubricating grease.
(2) Compressor oil (SAE 20 or 30) as per operator’s manual.
(3) Engine oil as per operator’s manual.

d. Essential Operating Spare Parts. List of these parts are generally recommended by suppliers or manufacturers. Parts should include at least:

(1) Solenoid valve assemblies and repair kits.
(2) Insecticide line tubing, ferrules and sleeves.
(3) Seals and gaskets.
(4) Flow meters and flow meter repair kits.
(5) Constant delivery pumps and repair kits.
(6) Insecticide and fuel strainer.
(7) Replaceable nozzle assembly components.
(8) Replaceable engine ignition parts.
(9) Air filters for carburetors and compressors.
(10) Replaceable electronic circuit boards and components.

e. Preparation for Storage of Engine/Blower Units. Before storing the aerosol generator the following preparations should be made:

(1) Prepare the insecticide metering system for storage according to instructions in its manual.

(2) Remove the cover and screen on the air intake silencer. Start the engine and pour one pint of lubricating oil (SAE 40) into the blower intake. Shut the engine down immediately.

Replace the cover and screen. The oil will coat the entire inner surface of the blower. This will prevent a coat of rust from forming in the blower and will save the cost of a new blower or an expensive repair bill.

(3) Drain the engine carburetor.

(4) Store the aerosol generator under suitable cover so it is protected from the elements.

APPENDIX A

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APPENDIX B

INSTRUCTIONS FOR DETERMINING FLOW RATE

A. General

1. Two people are needed to measure flow rate.

2. A minimum of two gallons of insecticide, Mineral oil to simulate oil-based insecticides or water to simulate water-based insecticides in the tank is necessary.

3. Two containers are needed. The large container can be a used plastic bleach or milk bottle with a portion of the top section cut away but leaving the handle. The small container must be a graduated cylinder, capable of measuring a minimum of eight fluid ounces or 250 milliliters.

4. Stop watch.

B. Instructions

1. Start the engine. Set the operating air pressure after the machine has warmed up, usually five psi.

2. Turn on the solenoid valve by activating the toggle switch.

3. Open the flow control valve. Be sure that there are no bubbles in the lines and all insecticide lines are filled.

4. Cut off the solenoid valve.

5. Use protective gloves for all subsequent steps. Disconnect the insecticide discharge tube from the fog head. Hold both containers in one hand at the same level as the discharge tube connection, and place the discharge tube over the large container. The discharge line must be held steady during flow rate measurement.

6. Turn on the solenoid valve, and set the flow control valve to the flow rate in the manual closest to the desired flow rate for the specific insecticide you are using. Allow insecticide to flow into the large container to ensure steady flow and stabilization of temperature.

7. Record flow control valve setting, air pressure, liquid and air temperatures.

8. The person operating the controls will time the flow rate by signaling the person holding the discharge tube to shift it from the large container to the graduate. Timing of flow starts at this instant. Time the flow for 30 seconds. At the end of 30 seconds, signal transfer of the insecticide line back to the large container. Cut off the solenoid valve.

9. Observe the measured flow, and multiply the result by 2 to get the flow rate per minute. Alternatively, 1- or 2-minute readings can be used for low flow rates, but the volume is then divided by 1 or 2 minutes, respectively, to give the rate. Increase or decrease the flow control valve setting to obtain the correct flow rate by repeating steps 6, 7 and 8 above.

10. Reconnect the insecticide line to the fog head, lock the flow control valve and record the settings.

12. Alternate method of measuring flow rate is to fill the spray tank to a marked level, spray for two minutes and fill the tank to the same level with the known volume. Diving by 2 the volume required to fil the tank will give flow rate.

11. Flow rate variations occur from machine to machine. Therefore, a calibration chart based on liquid temperature must be made for your particular machine. Record flow control valve settings for each five degrees of temperature between 60 and 100 degrees while maintaining the proper insecticide flow rate. These temperatures can be obtained starting early in the morning and progressing through the day.

C. Cleaning Instructions

1. Remove the filler cap to prevent pressure buildup on the insecticide tank.

2. Remove the insecticide discharge line at the tank. Place this line in a container with approximately one pint of isopropyl alcohol.   DO NOT USE ACETONE

D. Cleaning the Machine

1. Remove the air pressure line on the insecticide tank to prevent accidental discharge of contents.

2. Start the machine. Turn on the solenoid valve and adjust the flow control valve to the highest setting. Run the machine until all the alcohol is exhausted.

APPENDIX C

EQUIPMENT CALIBRATION DATA SHEET

Note: Be sure to calibrate the machine before collecting droplet samples.

Please record the following information:

1. Date ____
2. Machine type, manufacturer, serial number________________________________
3. Machine flow rate in ounces or milliliters per minute__________________________
4. Machine air pressure ____
5. Machine liquid temperature____
6. Outside air temperature____
7. Flow meter setting____
8. Insecticide used____
9. Wind speed (MPH)____

APPENDIX D

Testing Results of Spray Equipment Used in Vector Control

A. Introduction

1. The testing and evaluation of pest management equipment used for vector control in theater operations, humanitarian efforts and on military installation is one of the primary missions of the U.S. Navy's Naval Entomology Center of Excellence (NECE) at NAS JAX in Jacksonville, FL. Besides testing the operation, safety, and durability of spray equipment, the performance characteristics of equipment are also tested. These performance characteristics include precision of flow rate control and the droplet spectra generated by the equipment. The assessment of droplet spectra has been traditionally done by either a hot-wire droplet measurement system (DC-III (AIMS), KDL labs, Inc) or by waving a glass slide through the spray and capturing droplets on either Teflon, magnesium oxide, or silicon-coated slides. Another method for measuring droplet size is with laser diffraction equipment such as that used by the USDA-ARS's Aerial Application Technology group in College Station or Phase Doppler Particle Analyzer (PDPA) as used by NECE.

2. In a joint effort between NECE and USDA, a series of equipment evaluations were started in 2005 with the goal of evaluating the droplet spectra generated by spray application equipment used by military personnel to control arthropods. Most of the equipment was evaluated with water- and oil-based insecticides, mineral oil or water under a variety of flow rates and/or pressures. The objectives of this work were to present not only information on spray system droplet size generated by different sprayers, but also to present a methodology by which other similar systems can be evaluated to provide applicators with sprayer system performance data. There was a range in droplet sizes generated by the different sprayers with the different spray solutions tested. These data allow users to select the spray solution and sprayer that generates the droplet size spectra that meet their specific spray application scenarios. For example, if an applicator is making a barrier control application where the desired result is that droplets impact and are retained on the surface, a sprayer that generates larger droplets (i.e. > 40 µm) would be selected. If the application called for a spray that moves laterally downwind to impact flying insects, a sprayer that generates a spray cloud with a volume median diameter (VMD) between 3 to 25 µm would be selected. This work provides a database detailing the droplet size characteristics resulting from equipment, operational settings, and spray formulation combinations which aid and support decisions made by field users.

3. To date, over 123 pieces of equipment have been tested including all equipment with National Stock Numbers (NSN). The equipment tested can be divided into hand-held/backpack, truck-mounted, and thermal fogging categories. Most of the sprayers were tested for three flow rates covering their entire range of flow rate and all operating pressures. Also most of the sprayers were tested using BVA-13 mineral oil as simulated oil-based insecticide or water plus a surfactant as simulated water-based insecticide. Some of the sprayers were tested while spraying insecticides. All of the data have been reported by Hoffmann et al. (2007a; 2007b; 2008, 2009, 2012) and Farooq et al (2016).

4. Most of the data is also available in the form of an App called "Vector Spray). This app is a searchable database of all the published work on droplet characterization resulting from collaborative work between the US Navy Entomology Center of Excellence (NECE), Jacksonville,

FL and Aerial Application Technology, Areawide Pest Management Research Unit, Southern Plains Agricultural Research Center, ARS, College Station, TX. This app allows users to select their specific sprayer, operating conditions, and spray solution then displays the spray droplet size. Once downloaded, users do not need to have internet connection to use it. The iphone version of the app is available on the iTunes store for free download. The companion Android version of the app is also publically available for free download.

5. For data on any spray equipment, not available through these sources can be obtained by contacting NECE.

APPENDIX E

DIRECTIONS FOR DETERMINING PARTICLE SIZE OF AEROSOLS AND FINE SPRAYS

1. Excellent reviews of particle measurement have been published by Yeomans (1949), Matthews (1992) and Rathburn (1970), which are adopted in the sections below. Additional information may be obtained from references in their bibliographies. Specific guidelines for droplet measurement can also be obtained from the Navy Entomology Center of Excellence (below). If assistance is required in collecting droplets or analyzing prepared slides, please contact one of the following for assistance:

a. Navy:

Officer in Charge, Navy Entomology Center of Excellence, ATTN: Testing and Evaluation, Box 43, Bldg 931 Child St, Naval Air Station, Jacksonville, FL 32212

b. Army:

Commander, USAPHC-North, Entomological Sciences, ATTN: MCHB-AN-ES, Bldg 4411, Ft George G. Meade, MD 20755-5225

Commander, USAPHC-South, Entomological Sciences, ATTN: MCHB-AS-ES, 2472 Schofield Road, 2nd Floor, Fort Sam Houston, TX 78234-6233

Commander, USAPHC-West, Entomological Sciences, ATTN: MCHB-AS-ES, Box 339500-MS 115, Ft Lewis, WA 98433-9500

2. A "Hot Wire" instrument using equipment such as the KLD Labs DC-IV Droplet Analyzer, provides a quick means of determining droplet size data for ULV sprayers. The hot wire method takes <15 minutes and provides an instantaneous readout on the spectrum of droplet sizes. Newer hot wire systems have electronic data collection systems, which can be downloaded onto a computer for record keeping and digital display of data. The hot wire is actually a thin metal filament that is very delicate and therefore easily broken, so extreme care is needed when using such a system.

3. Impinged slide analysis. The best method that has been found for determining the particle size of insecticidal aerosols and fine sprays is to deposit a sample on a glass slide and measure the particles under a high-power microscope. The following directions for determining droplet sizes and other spray cloud characteristics is taken from a report from the United States Department of Agriculture, Agricultural Research Administration, Bureau of Entomology and Plant Quarantine (ET-267, May 1949) written by A.H. Yeomans. This paper describes in detail the technique as it is now used, and should contain most of the information needed to determine important droplet size and spray cloud parameters.

Aerosol Droplet Analysis Test Kit Components*

(*Mention of a product or supply source does not constitute an endorsement of the products named or criticism of similar ones not mentioned. Mention of trade names does not constitute a guarantee or warranty of the products by the AFPMB, the Military Services, or the Department of Defense.) Other suppliers could be found through internet.

An inexpensive droplet analysis kit can be produced using the following components:

1. Four foot long ¾ inch diameter or 1 inch diameter wooden dowel
2. One each ¼ inch diameter X 1 ½ inch long bolt (can use 10/32 inch up to ¼ inch diameter bolt)
3. Two flat washers, ¼ inch (or size to match other diameter bolts, if used).
4. One wing nut, ¼ inch

Note. Use the above materiel to construct a wooden dowel stick with slotted end, bolt, washers, and wing nut to clamp slides into the slotted stick. Cut a slit, using a saw, approximately 4 inches long in one end of the dowel so that it can hold a slide. Next drill a hole, using a drill bit which matches the diameter of the 1 ½ inch bolt, through the dowel approximately 3 inches down from the dowel end with the slit. Microscope slides placed one inch into the slit can then be tightened into the slit using a ¼ inch x 1 ½ inch bolt inserted into the drilled hole and fastened with washers and wing nut. Wood dowel, bolts, flat washers, and wing nuts can be purchased at a local hardware store.

5. Graduated Cylinder, polypropylene economy graduated, size 250 ml. The graduated cylinder is used for measuring flow rates. A source is:

> Fisher Scientific
> Phone: 1-800-766-7000
> Nalgene polypropylene economy graduated cylinder
> Catalogue No. 08-572-6E
> Unit Price - $12.84 each, Case of 12 for $94.71

6. A set of Teflon®-coated or Magnesium coated slides, cover slides, and spacers should be obtained for droplet collection. Teflon®-coated slides are used to collect particle of relatively nonvolatile droplets while Magnesium oxide slides are used for measuring particles of volatile materials, which evaporate rapidly, from the size of the craters they leave at the points of contact on slides. Careful attention to the instructions will allow you to effectively evaluate your equipment. Distributors of aerosol droplet samplers and coated microscope slides (Teflon- and magnesium oxide).

> BioQuip Products
> 2321 Gladwick Street
> Rancho Domingues, CA 90220
> Phone: (310) 667-8800
> Fax: (310) 667-8808

Email: bqcustserv@bioquip.com

Slide Cost: $115.92 for a box of 25 or $24.52 for a box of 5.

John W. Hock Company
7409 NW 23rd Avenue
Gainesville, Florida 32606
Phone: 352-378-3209
Email:sales@johnwhock.com

Slide Cost Teflon®-coated: $75.00 for a box of 24.
Slide Cost Magnesium Oxide coated: $70.00 for a box of 24.

LeadingEdge Associates, Inc
702 Tulip Tree Ct.
Fletcher NC 28732
Phone: (828) 400-7328
Email:Smorris@LeanTeam.com

Slide Cost Teflon®-coated: $115.00 for a box of 25.

7. Cover slides (NSN 6640-00-494-3808)

8. Mailer and/or shipper tubes:

Fisher Scientific
Phone: 1-800-766-7000
Catalogue No. 03-526: $248.00 for 300 foam mailers that hold 10 slides each
Catalogue No 03-526A: $296.76 for 300 mailing sleeves for 03-526 above

9. Paper gasket. Make paper gaskets, using manila folders, 3/5 cards or copy paper. First cut the gasket materiel to the same dimensions as the slide (1"x3"). Then carefully cut out the center so that you have a "window frame" effect. The edges of the "window frame" should be about ¼ inches thick. This gasket is used as a spacer between Teflon-coated slide and the 1"x 3" slide used as a cover.

10. Tape. Cellophane tape is commonly found in most convenience stores. Use cellophane tape at both ends of the slide and wrap it securely.

11. Cleaning Brush, size 2-inch diameter x 6-inch long brush, with overall length of 20 inches. Brush is used to clean graduated cylinder after use.

Fisher Scientific
Nessler tube brush
Catalogue No 03-621-B
Cost: $20.28 each; Pack of 12 EA for $331.80

12. Reading Slides

a. A magnification of 100X is recommended when performing droplet measurements, although many workers use a magnification of 400X. This practice is satisfactory for uncovered slides, but difficult to achieve with covered slides.

b. For field or contingency operations, a 100X magnifier may be used as an alternative to a more expensive, heavy and often difficult to obtain compound microscope. Using this device and a fixed spread factor, field measurement and assessment of droplet spectra can be satisfactorily performed with minimal measurement error.

c. Eyepiece (ocular) micrometer with etched scale of 100 numbered divisions that fit into the eyepiece's base. Note: Prior to purchase, ensure that the micrometer will fit into the model of the microscope with which it will be used. Cost is approximately $50.00.

d. Stage micrometer. Used to calibrate the ocular scale in the eyepieces. Glass slide, with a millimeter divided into 100 parts of 10 microns each. Approximate cost is $75.00 to $150.00. Note: Prior to purchase, ensure that the micrometer will fit the model of the microscope that it will be used with.

Deposition of Particles on Slides

A sample of an aerosol or spray cloud can be deposited on a slide by impingement or by settling.

Deposition by impingement may be accomplished by moving the slide through an aerosol or spray cloud, or by moving the aerosol or spray cloud past a slide in fixed position. The velocity of movement in either case must be adjusted to the particle size range expected. The velocity must be increased as the average particle size decreases. Since the deposition is in proportion to the particle size, compensation must be made for this factor. The Cascade and Micro impactors developed in England, wherein an aerosol cloud is drawn through a series of orifices to vary the velocity, and impinged on a different slide at each orifice, is useful only with very small particles, mostly out of the range of insecticidal aerosols and sprays.

Deposition by settling should be limited to particle size ranges below 20 microns in diameter. It may be accomplished by two means. An aerosol of spray cloud is released in an enclosure and allowed to settle onto slides placed on the floor or bottom. The cloud must be mixed to be uniform, and the aerosol or spray released in such a way as to prevent impingement on the sides or ceiling of the enclosure. The amount released should be small enough to prevent coalescing in the air or too heavy a deposit on the slide. Adequate time must be allowed for all the smaller particles to settle a distance equal to the height of the enclosure. Convection currents should be prevented as much as possible. A second and more rapid method is to draw the aerosol or spray cloud through an electrical precipitator in which slides have been placed. When the machine is turned on, all particles in the field are precipitated in a matter of seconds. Deposition by settling results in a slide representative of the entire range of particle sizes in the sample, with each size present in true proportion so that no adjustment or weighting is necessary.

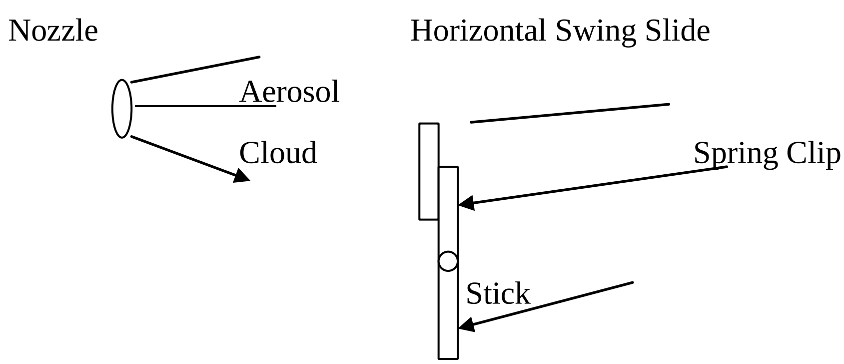
Procedure for Collecting Droplets from Aerosol Equipment

1. Proceed as follows:

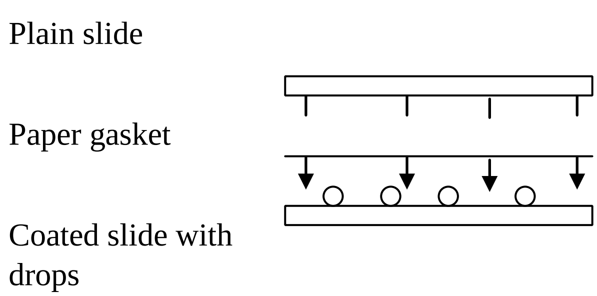
   a. Set the machine to the proper flow rate according to the instructions that come with the machine.

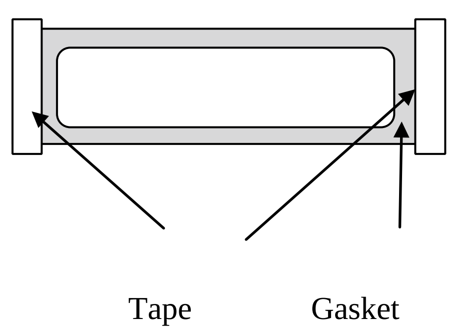
   b. Keep the fogging head to a horizontal position so the insecticide flow is parallel to the ground.

   c. With the machine operating properly, take three slide samples at eight (8) feet. The wind speed should not exceed ten mph for the test. The slide is attached to a wooden dowel stick. Wave the slide through the insecticide cloud perpendicular to the flow. The exposure time for the swing should be approximately one (1) second. The droplets must be collected on the numbered side of the slide, so face it towards the cloud.



   d. After the sample is obtained, put one of the spacing papers provided on the slide (slide number side up), and cover the paper and the exposed slide with a plain microscope slide, making a "sandwich" of the two slides and the paper.





e. Use cellophane tape at both ends of the slide and wrap it securely.

Note: If the slides are stored at room temperature and are to be transported locally, there is no need to cover and wrap the Teflon®-coated slides for reading within 21 days (Farooq et al. 2013). In that case, put slides in the storage box, close the box and store at room temperature. For the slides stored longer than an hour at temperatures above 45°C (113°F), correction factors are provided by Farooq et al. (2013) up to 100 hours.

f. Wrap the slides in tissue paper to prevent breaking and return them in the mailing box provided.

g. If there are any questions, contact NECE, DSN 942-4624, COM 904-542-4624.

2. Record pertinent equipment and weather information on the data sheet provided in Appendix C.

3. If unable to read and evaluate these slides yourself, submit slides to commands listed at the beginning of this section.

Microscope Eyepiece Micrometer Calibration

1. Measurement of objects with the microscope requires calibration of the instrument. Two scales are required: an ocular or eyepiece micrometer (a glass disc bearing a scale of 50 or 100 divisions numbered at intervals to facilitate reading), and a stage micrometer (a glass slide with a scale divided into units of 0.1 mm and 0.01 mm).

2. Remove eyepiece, unscrew the top lens, and note the circular shelf inside. Clean the eyepiece micrometer disc with lens paper and place it carefully in the eyepiece so that it rests on the shelf. Replace the top lens and insert the eyepiece in the microscope. With moderate illumination, the scale should be in sharp focus. If its numbers are backwards, the disc is upside down and must be turned over. This scale, regardless of the objective used, will appear the same size when viewed within the eyepiece, and must be calibrated for each lens combination (i.e. eyepiece and objective) provided by the microscope. The stage micrometer is used for that purpose. With the lowest power objective in position, place the stage micrometer on the stage and focus on its scale. The ruling may be in 0.01 mm units throughout its length or only at one end, with the remainder divided into 0.1 mm units. Rotate the eyepiece until its scale is either superimposed on, or very close and parallel to, the stage scale. Move the stage micrometer so that its zero line is exactly even with, or superimposed on, that of the eyepiece scale. Then, as far as possible from that point, find another at which the two scales coincide. Count the spaces on each scale between these points and determine the actual distance on the stage micrometer. That distance divided by the number of eyepiece spaces gives the actual length measured by one space on the eyepiece scale. Following is an actual calibration using a 10x eyepiece and a 16 mm (10x) objective:

100 eyepiece spaces = 65 stage spaces, each 0.01 mm long

100 eyepiece spaces = 0.65 mm

1 eyepiece space = 0.0065 mm or 6.5 microns

3. In the same manner, calibrate all other objectives of the microscope and record the values obtained. Because scale lines on the stage micrometer have appreciable thickness at high magnification, readings are more accurate if taken at their edges in finding points at which the two scales coincide. The calibration value is inversely proportional to the magnification. Thus, the distance measured by one eyepiece space with a 43x (4mm) objective is 10/43 that when the 10x (16 mm) objective is used. Actually, lenses vary slightly from their stated magnifications, making it necessary to calibrate each lens combination. Also, calibrations are accurate for a given instrument only if the length of the body tube remains unchanged.

Determination of Particle Size

1. After the sample of aerosol or spray has been deposited on a slide, it is placed under a microscope and the individual particles are measured with an eyepiece micrometer. A mechanical stage on the microscope is necessary. The diameter as measured on the slide is then corrected for the amount of spread that has taken place, and the diameter of the original sphere is determined.

2. At least 200 particles should be measured, according to DalaValle (1943). The more homogeneous the aerosol or spray, the fewer particles need be counted. All particles should be counted as they are seen in the field. An accurate method is to measure all particles from one edge of a slide to the other and that pass through the micrometer scale as the slide is moved by the mechanical stage. Under some conditions of impingement, particles of the smaller size groups are congregated along the margin of the slide. Measurements in such areas should be avoided.

3. It is sometimes useful to photograph the particles or to project them on a screen through a microscope. Better results have been obtained, however, by measuring the particles directly as seen in the microscope. It is often more convenient to measure in terms of the divisions of an eyepiece micrometer, and convert these divisions into microns after the median has been determined.

4. Step-by-step procedure for measurement of size of droplets on slides is provided by Robinson and Beidler (2000). The publication also explains data entries to the Aerosol Droplet Test Worksheet below.

5. There are computer programs into which you can input the count of eyepiece divisions and they will calculate the VMD. These will greatly speed the calculations, but you should become familiar with the longhand method. One such program can be downloaded free from REMSpC Consulting.

6. Impinged Slides. The rate of deposition on slides has been demonstrated to be proportional to square of the diameter. This rate of deposition was suggested by the Central Aerosol Laboratory

of Columbia University and was based on Sell's law. To compensate for the decrease in the rate of deposition as the particle decreases in size, each diameter is multiplied by the number of particles of that size, f and expressed as the percent of the total of such products. Sample data illustrating this method are given in Table E1.

7. The diameter is used in the first power only, since the particles impinge in the ratio to D^2, but the mass diameter is computed on the basis of their volume, which is a ratio to D^3. Therefore, the number of particles is multiplied by D^3/D^2, or by D.

Aerosol Droplet Test Worksheet

EYEPIECE DIVISIONS (D)	**TALLY**	**N**	**DN**	**%(DN/SDN)**	**% ACCUM**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
TOTALS					

8. The accumulative percentages from the last column are plotted on the arithmetic probability scales. The 50-percent point of the line so plotted is taken as the median of the particles as they appear on the slide. In this example the 50-percent point has a value of 2 scale divisions, or 30 microns, as each division we predetermined to equal 15 microns.

Table E1. Sample count of aerosol particles impinged on microscope slides.

Diameter (scale Divisions) [D]	**Number of Particles** [N]	**D x N**	**Percent of Total of D x N**	**Accumulative Percentage**
0.5	2	1	0.2	0.2
1.0	26	26	6.3	6.5
1.5	33	49.5	11.9	18.4
2.0	82	164	39.5	57.9
2.5	34	85	20.5	78.4
3.0	17	51	12.3	90.7
3.5	4	14	3.4	94.1
4.0	5	20	4.8	98.9
4.5	1	4.5	1.1	99.9
Total	**204**	**415.0**		

9. A correction factor must be determined for each slide. The original spherical droplet as it is impinged on the slide becomes a convex lens, and the extent of its spread from its original shape can be calculated by determining the focal length of the lens so formed. This method is described in Porton Report 2463 (May 1942), a digest of which is appended. In the example cited the correction factor is 0.40; therefore 30 microns x 0.40 gives a median particle diameter of 12.0 microns. ADAPCO has compiled a list of spread factors for various pesticides which can be accessed from their website.

10 Settled Slides**.** The median diameter of all the particles collected on a slide by gravitational settling or by electric precipitation is determined by calculating the volume of each particle. The diameter of the particles is measured in microns. The volume is determined by multiplying the cube of the corrected diameter by $\pi/6$, or 0.5236. The volume of the particles of each diameter is expressed as a percentage of the total volume. Sample data illustrating this method are given in Table E2. The accumulative percentages from Table E2 are also plotted on the arithmetic probability scale and the median particle diameter is determined to be 4.05 microns.

Table E2. A sample count of aerosol particles settled on a microscope slide. (Volume =1/6 $\pi D^3 = 0.5236D^3$)

Diameter (microns)	**Number of Particles**	**Volume (micron^3)**	**Percent of Total Volume**	**Accumulative Percentage**
1.4	1	1	0.01	0.01
2.1	55	267	3.3	3.31
2.8	101	1161	14.5	17.81
3.5	50	1119	14.0	31.81
4.2	57	2211	27.7	59.51
4.9	11	677	8.5	68.01
5.6	20	1838	23.0	91.01
6.3	4	524	60.6	97.61
7.0	1	180	2.3	99.91
Totals	300	7978		

(A digest of Porton Report No. 2463)

1. Use a compound high-power microscope.
2. Use a flat mirror.
3. Remove condenser.
4. Use outside light.
5. Focus on particle, and measure and record exact diameter.
6. Set reading on fine focus adjustment at zero.
7. Manipulate coarse focus adjustment and mirror until some distant object (window frame) is in as sharp a focus as possible, using the drop as a lens.
8. Then focus downward with fine focus adjustment until the drop is in clear focus. The difference between the No. 6 reading of the fine focus adjustment (zero) and the no. 8 reading is the focal-length change.
9. Compute f' (focal-length change) and 2A (diameter of particle)

Example: The diameter of a particle covering 4 divisions in an eyepiece micrometer (1 division = 15.4 microns) would be 4 x 15.4 microns, or 61.6 microns. With a focal-length change of 206 microns, the spread factor of the particle would be 206/61.6, or 3.3.

With this factor of 3.3, the correction factor (f'/2A) for this drop would be 0.40 (see below for spread-factor ratios).

Spread-Factor Ratios to Determine Correction Factor

f'/2A	Correction Factor	f'/2A	Correction Factor	f'/2A	Correction Factor
1.48	0.60	2.0	0.48	4.0	0.375
1.50	0.58	2.1	0.47	4.8	0.35
1.55	0.55	2.2	0.46	5.0	0.34
1.60	0.54	2.3	0.45	5.5	0.33
1.65	0.53	2.6	0.44	6.0	0.32
1.70	0.52	2.65	0.43	6.8	0.31
1.75	0.51	2.8	0.42	7.0	0.30
1.80	0.50	3.1	0.41	8.0	0.29
1.95	0.49	3.3	0.40	9.0	0.28
				10.0	0.27

Additional tips for measuring and analyzing droplets

(Refer to Aerosol Droplet Test (Sample) sheet below for examples in this section)

(1) Measure 100-200 droplets on an exposed slide. Several horizontal sweeps or observation of isolated portions, selected at random, near the center of the slide will be satisfactory. Record data on Aerosol Droplet Test Worksheet as shown above and described by Robinson and Beidler (2000). Mark the counts in groups of five to simplify the procedure. A laboratory type hand tally counter or similar device will aid in maintaining a running total of droplets. Record the individual size totals and the grand total at the bottom of the (N) column.

(2) Using ten droplets counted as part of the sample, determine the spread factor by the method described below. Droplets measured with a diameter of five or more divisions on the ocular scale will yield the most accurate results.

(3) Multiply the number of droplets in the (N) column by the corresponding eyepiece divisions for each size recorded. For example, 32 drops x 2 eyepiece divisions = 64. Record this number in the column marked "DN".

(4) Total the numbers in the (DN) column and record the number at the bottom of the page, for example 859.

(5) Divide each number in the DN column by the (DN) total, multiply by 100, and round the answers to the nearest whole number. For example 22 divided by 859 multiply by 100 = 2.56%, or 3%. Record this number in the (% DN/EDN) column.

(6) Accumulate the total by adding each number in the (% DN/EDN) column to the (% ACCUM) number in the extreme right hand column. For example: 03 + 07 = 10; 10 +11= 21. The total of this column must equal 100 percent.

(7) Using semi-log graph paper, plot the accumulated percent (Horizontal axis) for eyepiece division opposite to the eyepiece number (vertical axis). Plot each number until 100% is reached.

(8) Using a straight edge, draw a line through the dots for the "best fit."

(9) To determine the VMD, draw a vertical line from the 50% mark on the cumulative percent (horizontal) axis to the point where it intersects with the line drawn in (8) above. In this case, the intersection point will be exactly at the five (5) eyepiece division mark.

(10) Multiply this number by the calibrated size of the eyepiece division in microns. For the microscope used in this example, each eyepiece division equals five (5) microns, therefore 5 x 5 = 25 microns.

(11) Using the computed spread factor, correct for droplet spread. In this example 25 (microns) x 0.5 (computed spread factor) = 12.5 microns VMD. Computation of the spread factor for this slide is not shown, but selected for simplified calculations.

(12) Percentage of droplets above or below a given size may be computed by referring to the chart. For example, if the percent less than 18 microns is to be determined, divide 18 by 5 (microns in each eyepiece division), and then divide it again by the spread factor. 18 divided by 5 = 3.6, divided by 0.5 = 7.2. Locate 7.2 on the eyepiece division axis using a straight edge, and move across until this line intersects with the line drawn in (8) above. Draw a vertical line down from this point to locate the percentage, in this case 82%.

(13) Statistical Evaluation of Recovered Droplet Data. For routine evaluation of droplet data, collecting particles on impinged slides is satisfactory. Data recovered from settling chamber studies require the third power, or cube of the diameter, to be employed for particle assessment. This procedure is more involved mathematically. Additionally, there are a variety of statistical analyses that can be used to interpret the data.

Aerosol Droplet Test (Sample)

EYEPIECE DIVISIONS	TALLY	N	DN	%(DN/SDN)	% ACCUM
1	///// ///// ///// ///// //	22	22	03	03
2	///// ///// ///// ///// ///// ///// //	32	64	07	10
3	///// ///// ///// ///// ///// ///// /	31	93	11	21
4	///// ///// ///// ///// ///// ///	28	112	13	34
5	///// ///// ///// ///// ///// ////	29	145	17	51
6	///// ///// ///// ///// /	21	126	15	66
7	///// ///// /////	15	105	12	78
8	///// /////	10	80	09	87
9	///// ///	8	72	08	95
10	////	4	40	05	100
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
TOTALS			859		

AVERAGE DROPLET DIAMETER = __________________MICRONS

(TOTAL D x N / TOTAL NO. DROPLETS)

VMD calculation: 5 X 5 X 0.5 = 12.5 microns.

Dukes et al. (1993) published correction factors for mosquito adulticides and the following table is provided as a more current and accurate reference.

Table 1. Table of correction factors(2r/2A)[1] for various spread factors (f'/2A)[2] for liquids having a refractive index of 1.5.

f'/2A	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	1.00	.98	.96	.95	.94	.93	.91	.89	.88	.86
1.1	.85	.84	.83	.82	.81	.80	.79	.78	.77	.76
1.2	.75	.74	.73	.72	.71	.70	.69	.69	.68	.67
1.3	.66	.66	.65	.64	.63	.63	.62	.62	.61	.61
1.4	.60	.60	.59	.59	.59	.58	.58	.58	.57	.57
1.5	.57	.56	.56	.56	.55	.55	.55	.54	.54	.54
1.6	.54	.53	.53	.53	.53	.53	.52	.52	.52	.52
1.7	.52	.51	.51	.51	.51	.51	.51	.51	.51	.50
1.8	.50	.50	.50	.50	.50	.50	.50	.49	.49	.48
1.9	.49	.49	.49	.49	.49	.49	.48	.48	.48	.48

[1]Correction Factor = $\frac{\text{2 X radius (r) of a spherical droplet}}{\text{diameter of droplet lens (2A)}}$

[2]Spread Factor = $\frac{\text{focal length change (f') from the base to the top of the droplet lens}}{\text{diameter of the droplet lens (2A)}}$

The following tables from Dukes et al. (1993) provide correction factors for common insecticide formulations.

Table 3. Correction factors for aerosol droplets collected on Teflon® coated microscope slides from six different batch samples[1] of Cythion® determined within a two day period of May, 1993.

DATE[2]	MANUFACTURER BATCH NUMBER	PERCENT MALATHION	Lbs. AI per gallon	CORRECTION FACTOR
08-1479	*	91.0	9.33	0.69
3-18-83	*	91.0	9.33	0.68
2-22-87	*	91.0	9.33	0.69
06-10-88	W805258261	91.0	9.33	0.68
03-27-89	W901248105	91.0	9.33	0.68
05-07-92[3]	30020122-03	95.0	9.79	0.68

[1]Batch samples of Cythion maintained at JAMSRL for reference.
[2]Date shipment received at JAMSRL, Panama City, Fl.
[3]Distributed by Cyanamid and manufactured by Cheminova of Lemvig, Denmark.
*Batch number not available.

Table 4. Correction factors for aerosol droplets of insecticides, formulations and diluents deposited on Teflon® coated slides.

INSECTICIDE (FORMULATION)	DILUTION RATIO (percent volume)	CORR. FACTOR	INSECTICIDE (FORMULATION)	DILUTION RATIO (percent volume)	CORR. FACTOR
CARBAMATES			PYRETHROIDS		
Baygon 1 MOS	Undiluted	0.66	Biomist 4 + 20	Undiluted	0.56
Ficam ULV	Undiluted	0.66	Oman 10	Undiluted	0.61
			Permanone 10 EC	Undiluted	0.56
ORGANOPHOSPHATES			Permanone 10 EC/Orchex Oil	50.0/50.0	0.55
Baytex	Undiluted	0.75	Permanone 10 EC/Orchex Oil	66.7/33.3	0.57
Baytex/Soybean Oil/Diesel Oil	1.5/33.5/65.5	0.58	Punt 10 R200-ND	Undiluted	0.59
Cythion 91 %	Undiluted	0.68	Pyrocide Fogging Formula	Undiluted	0.61
Cythion 95 %	Undiluted	0.68	SBP 1382 40MF	Undiluted	0.66
Cythion/Diesel Oil	6.0/94	0.58	SBP 1382 49MF/Klearol	9.0/90.0	0.61
Cythion/Soybean Oil	25.0/75.0	0.64	SBP 1382 40MF/Soibean Oil	40.0/60.0	0.59
Cythion/SBP-1382-40MF/Soy Oil	27.7/0.3/75.0	0.61	Scourge/BVA-13 Oil	20.0/80.0	0.65
Cythion/SBP-1382-40MF/HAN	34.0/1.0/65.0	0.70	Scourge/Klearol	59.5/40.5	0.60
Cythion/SBP-1382-40MF/HAN	58.0/1.0/41.0	0.70	Scourge/Klearol	2.9/97.1	0.60
Dibrom 14	Undiluted	0.72	Scourge/Soybean Oil	59.5/40.5	0.63
Dibrom 14/HAN	10.0/90.0	0.63	Scourge/Sotbean Oil	2.9/97.1	0.63
Dibrom 14/Soybean Oil	10.0/90.0	0.63			
Dibrom 14/Soibean Oil	25.0/75.0	0.63	OILS and DILUENTS		
Dibrom 8 EC/Water/Nalco-Trol	28.0/71.9/0.1	0.70	BVA-13 Oil	Undiluted	0.54
Dow Mosquito Fogging Conc.	Undiluted	*	Heavy Aromatic Naphtol	Undiluted	*
Dursban One ULV Mosquitocide	Undiluted	0.59	Soybean Oil	Undiluted	0.63
Dursban 1.5 ULV Mosquitocide	Undiluted	0.60			

*Droplets evaporate too rapidly to determine spread factor.

APPENDIX F

SOURCES OF SUPPLY FOR
ULV AEROSOL INSECTICIDE SPRAY EQUIPMENT AND NOZZLES*

A. Primary ULV Dispersal Equipment Manufacturers

1. ADAPCO, 550 Aero Lane, Sanford, FL 32771. Phone: (800)367-0659, Fax: (866)330-9888. Email: Info@MyADAPCO.com, Truck mounted and hand-held sprayers.

2. Clarke, 675 Sidwell Court, St. Charles, IL 60174, Phone: (630) 326-4633. Truck mounted and hand-held sprayers.

3. Curtis Dyna-Fog Ltd. P.O. Box 297, Westfield, IN 46074. Phone: (317) 896-2561. Truck mounted, and hand-held sprayers and thermal foggers.

4. London Foggers Company, 505 Brimhall Ave., Long Lake, MN 55356. Phone: (612) 473-5366, FAX: (612) 473-5302. Truck mounted and hand-held 5587992sprayers.

5. B&G Equipment Company, 135 Region South Drive, Jackson, GA 30233, Phone: (678) 688-5601, Fax: (678) 688-5633. Truck mounted, and hand-held sprayers and thermal foggers.

*Mention of a product or supply source does not constitute an endorsement of the products named or criticism of similar ones not mentioned. Mention of trade names does not constitute a guarantee or warranty of the products by the AFPMB, the Military Services, or the Department of Defense.

B. Additional Spray Equipment Manufacturers

Manufacturer Name	Address	Phone	Fax	Email	Website
Aakar Exports	401, Shantam Complex, Opp. Navneet House, Gurukul Road, Gujarat, INDIA	91-79-40054009		aakarexports@hotmail.com	akarexport.net
Ag Spray Equipment, Inc.	3303 Pembroke Road, Hopkinsville, KY 42240	270-886-0296	270-885-7392	agspray@agspray.com	agspray.com
AgSouth	2315 North Fifth St., Union City, Tennessee 38261	731-885-3806	731-885-3813	info@agsouthco.com	agsouthco.com
Air-O-Fan	507 East Dinuba Avenue, Reedley, California, 93654	559-638-6546	559-638-9262	info@airofan.com	Airofan.com
American Spring & Pressing Works Pvt Ltd	Aspee House, B.J. Patel Road, Malad West, Mumbai - 400064., Maharashtra, India	91-22-28822331	+91-22-28822336	Email: aspee@aspee.net	aspee.com
AMS Inc.	105 Harrison Street, American Falls, ID 83211	800-635-7330	208-226-7280	ams@ams-samplers.com	ams-samplers.com
BioRational Vector Control, LLC	7575 Tamra Drive, Reno, Nevada 89506	775)972-4782	775)972-8254	dariaz@aol.com	biorationalvectorcontrol.com
B & G Chemical & Equipment Company, Inc	10539 Maybank, Dallas, TX 75220	214)357-5741	214) 357-1024		
BEI, Incorporated	1375 Kalamazoo Street South Haven, MI 49090	269-637-8541	269-637-4233	info@bei-inc.com	bei-inc.com
Berthoud Sprayers	EXEL Gsa – BP 424 - 69653 VILLEFRANCHE s/s Cedex, FRANCE	+33 (0)4 74 62 48 30	+33 (0)4 74 62 37 51		berthoud.fr/en/
Birchmeier Spruhtechnik AG	Im Stetterfeld 1, 5608 Stetten, Schweiz	+41 56 485 81 81	+41 56 485 81 82	info@birchmeier.com	birchmeier.com
Braglia Srl	via Martin Lutero, 4 – 42029, Reggio Emilia, Italy (UE)	+39 0522 340648	+39 0522 340897	braglia@braglia.it	braglia.it
Buffalo Turbine	180 Zoar Valley Road, Springville, NY 14141	716-592-2700	716-592-2460	info@buffaloturbine.com	buffaloturbine.com
C & S Turf Care Equipment	P.O. Box 36717, Canton, OH 44735	330-966-4511			csturfequip.com
Chema Industries	3 El Fawatem Street, Pharana 21521, Alexandria, EGYPT	+203 4810498	+203 4810499	info@chema.com.eg	chema.com.eg
CIMA. S.p.A. - Loc. Molino Quaroni	27040 - Montu' Beccaria (PAVIA) - Italia	+39-0385-246636		info@cima.it	cimaitalia.it
CNH Industrial	6900 Veterans Blvd, Burr Ridge, IL 60527	630-887-2233			cnhindustrial.com
Contree Sprayer @ Equipment Co.	W9898 Jackson Rd, Beaver Dam, WI 53916	800-433-3579		sales@contree.com	contree.com
Croplands Equipment	50 Cavan Road, Dry Creek SA 5094, Australia	1800 999 162		sales@croplands.com.au	croplands.com.au
Deere & Company	One John Deere Place, Moline IL 61265-8098	309-765-8000			deere.com/en/
DEMCO Mfg Company	4010 320th Street, Boyden, IA 51234	800-845-6420			demco-products.com
Durand-Wayland	P.O. Box 1404, LaGrange GA 30241	706-882-8161	706-882-0052		durand-wayland.com

B. Additional Spray Equipment Manufacturers (Cont…)

Manufacturer Name	Address	Phone	Fax	Email	Website
FIMCO	200 South Derby Lane, North Sioux, SD 57049	800-831-0027	800-494-0440		Fimcoindustries.com
Fogmaster Corporation	1051 SW 30th Avenue, Deerfield Beach, FL 33442	954-481-9975	954-480-8563	info@fogmaster.com	fogmaster.com
F/S Manufacturing Inc.	1102 Center St., West Fargo, ND 58078	800-333-2314	701-281-1412	fsmfg@fsmfg.com	fsmfg.com
Garrards Pty Ltd.	32 Kenworth Place, Queensland 4500, Australia	+61 7 3881 1693			garrards.com.au
Gempler's	P.O. Box 5175, Jamesville, WI 53547-5175	800-382-8473		customerservice@gemplers.com	gemplers.com
GNC Industries, Inc.	1401 Pace Rd., Pocahontas, AR 72455	870-248-9901	870-248-9905	sales@gnci.org	gncindustries.com/
Goldacres	3 Morang Crescent, Mitchell Park Vic 3355	03 5342 6399	03 5342 6308	info@goldacres.com.au	goldacres.com.au/
GPS Sprayers Ltd	Unit 11 Chancerygate Business Centre, Langford Lane, Kidlington OX5 1FQ, United Kingdom	+44 1865 841341		enquiries@gps-sprayers.co.uk	gps-sprayers.com
GreenTech	108-112 Wing Street, WINGFIELD, South Australia 5013	61 8 8359 5362	61 8 8359 5364	sales@greentechspraysystem.com	greentechspraysystem.com
Hagie	721 Central Ave. W. Clarion, IA 50525				hagie.com
HARDI North America	1500 W 76th St, Davenport, Iowa 52806	563-386-1730	563-386-1280	info@hardi-us.com	hardi-us.com/na/
H. D. Hudson Manufacturing Company	1000 Foreman St. SE, Lowell, MI 49331	800-977-7293		ladybug@hdhudson.com	hdhudson.com
Bertolini Pumps	Via Fratelli cervi, 35/1–42124, Reggio Emilia (RE), ITALY	+39 0522-306641	+39 0522-306648	email@bertolinipumps.com	bertolinipumps.com
J.F. Oakes		662-746-7276	662-746-4568	sales@jfoakes.com	jfoakes.com
Jacto Inc.	19217 SW 19th Ave, Tualatin, Oregon 97062	800-522-8610	800-511-3671	info@jacto.com	jacto.com
Chalfoun Agri. Products	P.O.Box: 1 Akaybe, Keserwan. Lebanon.	+961 9 444393	+961 9 440257	contact@chalfoun.com	chalfoun.com
KB Manufacturing, LLC	35545 290th St. SW, Fisher, MN 56723	218-289-0736		kbmfg@rocketmail.com	rrv.net/kbmfg
McConnel	Temeside Works, Ludlow, SY8 1JL England	+44 1584 873131	+44 584 876463	sales@mcconnel.com	mcconnel.com
Kisan 76	Post Box. No. 125, Ludhiana - 141008, (PB) INDIA.	+91-161-2749508,		kisan76@yahoo.co.in	kisan76.in
Leinbachs, Inc	262 Northstar Dr, suite 162 Rural Hall N.C. 27045	336-969-0359			leinbachs.com
MAROLEX Sp.z o.o.	ul. Reymonta 2, 05-092 Dziekanów Leśny k. Warszawy, Poland	+48 22 732 23 51	+48 22 751 0227	info@marolex.pl	garden-sprayers.com
Maruyama U.S.	4770 Mercantile Dr., Fort Worth, TX 76137	940-383-7400	940-383-7466	maruyama@maruyama-us.com	maruyama-us.com
The McGregor Company	28232 Endicott RD, Colfax, WA 99111	800-727-9160	509-397-6306	mcgregoreq@mcgregor.com	mcgregoreq.com
Metallurgy Prapopoulos Bros S.A.	Aristotelous 123, 263 35, Patras, Greece	+30 2610 641 642	+30 2610 641 641		prapopoulos.com
Michigan Metalcraft LLC	1008 Court st., Clare MI 48617	989-429-5381		info@farmspraying.com	farmspraying.com

B. Additional Spray Equipment Manufacturers (Cont…)

Manufacturer Name	Address	Phone	Fax	Email	Website
Micron Group	Bromyard Industrial Estate, Bromyard, Herefordshire, HR7 4HS, U.K.	+44 1885 482397	+44 1885 483043	enquiries@micron.co.uk	microngroup.com
New Mountain Innovations	6 Hawthorne Rd Old Lyme, CT 06371	860-691-1876		sales@newmountain.com	newmountain.com
Norris Wiener	90 Chelmsford Road, North Billerica, MA 01862	978-670-2501	978-670-5633	info@norriswiener.com	norriswiener.com
On Target	395 South Main Street, Mt. Angel, OR 97362	503-996-1101		info@ontargetspray.com	ontargetspray.com
PBM Supply & Mfg., Inc.	324 Meyers Street, Chico, CA 95928	800-688-1334	530-345-9903	pbm@pbmsprayers.com	pbmsprayers.com
Pentair	375 5th Ave NW, New Brighton, MN 55112	800-445-8360			hypropentair.com
Phesco International LLDF	7341 Caribou St., San Antonio, TX 78238	210-532-9331	210-532-9703	charlie@phesco.com	phesco.com
Progressive Ag Inc.	1336 McWilliams Way, Modesto, California 95351	800-351-8101	209-567- 3233		proaginc.com
Proptec (Ledebuhr Industries)	101 Innovation Parkway, Williamston, MI 48895	866-641-4671	888-636-8635	info@ledebuhr.net	proptec.com
R&D Sprayers (Bellspray, Inc)	419 Hwy 104, Opelousas, LA 70570	337-942-1001	337-942-7841	rdspray@co2sprayers.com	co2sprayers.com
Real Fleet Solutions	605 Townsend Road, Cocoa, FL 32926	800-940-8024		info@realfleetsolutions.com	www.realfleetsolutions.com
Red Ball LLC	2205 Hall Ave., Benson, MN 56215	320-843-1700	320-843-1703		willmarfab.com
Sands Agri Machinery Ltd	Main Road, Brunstead, Stalham, Norwich NR12 9ER, UK.	+44 1692 580522		sales@samltd.co.uk	samsprayers.co.uk
Slimline Manufacturing	559 Okanagan Ave E, Penticton, BC Canada V2A 3K4	800-495-6145		orders@slimlinemfg.com	slimlinemfg.com
Spectrum Electrostatic Sprayers Inc.	7500 San Felipe, Suite 860, Houston, Texas 77063	713-783-5771	713-783-5772	spectrumsprayers@comcast.net	spectrumsprayer.com
Spray Innovations	7240 County Rd. AA, Quinter, KS 67752	785-754-3513			sprayinnovations.com
Sprayer Specialties Inc	4151 SE Capitol Circle, Grimes IA 50111	800-351-1587	515-9869257	info@sprayers.com	sprayers.com
Swingtec GmbH	Achener Weg 59, 88316 Isny - Germany	+49 7562 708-0	+49 7562 708-111	info@swingtec.de	www.swingtec.de
Taizhou Luqiao Ziqiang Sprayer Factory	Pengjie Industrial Zone, Luqiao District, Taizhou City, Zhejiang, China	86-576-82723679	86-576-82723678	ziqiang@zqsprayer.com	www.zqsprayer.com
Wylie Sprayers	14200 E. I-40, Amarillo, TX 79118	888-788-7753			wyliesprayers.com
Yuma Farm & Home Supply	2222 E 16th St, Yuma, AZ 85365	928-329-9113	928-329-0281	yumafarmhome@aol.com	sunsprayers.com

C. Nozzle Manufacturers

Manufacturer Name	Address	Phone	Fax	Email	Website
BETE Fog Nozzle, Inc.	50 Greenfield Street, Greenfield, MA 01301	800-235-0049	413-772-6729	sale@bete.com	bete.com
Bex Inc.	836 Phoenix Drive, Ann Arbor, Michigan 48108	734-389-0464	734-389-0470	sales@bex.com	bex.com
CP Products (Transland)	1206 Hatton Rd Suite A, Wichita Falls, Tx 76302	940-687-1100	940-687-1941	sales@translandllc.com	translandllc.com
dlh Bowles	6625 Dobbin Road, Columbia, MD 21045	410-381-0400	410-381-2718	info@dlhbowles.com	dlhbowles.com
Delavan Spray Technologies	4334 Main Hwy, Bamberg, South Carolina 29003	800-982-6943	803-245-4146	delavansales@goodrich.com	delavaninc.com
Greenleaf Technologies	P.O. Box 1767, Covington, LA, 70434	800-881-4832	985- 898-0336	sales@greenleaftech.com	greenleaftech.com
Jasmic	PO Box 369, Hazlet, New Jersey 07730	888-452-7642	732-888-5552	info@jasmic.net	jasmic.net
Lechler, Inc.	445 Kautz Rd., St. Charles, IL 60174	800-777-2926	630-377-6657	info@lechlerusa.com	lechlerusa.com
NESCO	7 Hampshire Drive, Mendham, NJ 07945	973-543-4586	973-543-4588	info@drdust.com	drdust.com
Orthos Liquid Systems, Inc.	P.O. Box 1970, Bluffton, SC 29910	843-987-7200	843-987-7203		orthosnozzles.com
Pem Fountain	104 Newkirk Road, Richmond Hill, ON L4C 3G3	800-387-3600	905-884-8941	sales@pemfountain.ca	pemfountain.ca
PNR America LLC	1 Civic Center Plaza St 303 Poughkeepsie, NY 12601	845-483-7770	845-483-7755	info@pnramerica.com	pnramerica.com
Pro Dyne Corporation	136 Green Tree Road, Suite 100 Phoenixville, PA 19460	888-776-3963 610-789-0606	610-789-7007	prodyne@prodynecorp.com	prodynecorp.com/index.html
Quality Spray Products Co.	478 W Wrightwood Ave, Elmhurst, IL 60126	630-530-0170			
Rexnord Industries	4701 West Greenfield Avenue, West Milwaukee, WI 53214	414-643-3000 866-739-6673			https://www.rexnord.com/home.aspx
RL Flow Master	1000 Foreman Road, Lowell, MI 49331-1074	616-897-9211	616-897-8223	rlservice@rlflomaster.com	rlflomaster.com
Spraying Systems Co.	200 W. North Ave., Glendale Heights, IL 60139	630-665-5000	630-260-0842		spray.com
STEINEN	29 E. Halsey Rd., Parsippany, NJ 07054	973-887-6400	973-887-4632	inquiries@steinen.com	steinen.com
Wilger Inc	255 Seahorse Drive , Lexington, TN 38351-6538	877-968-7695	877-968-7613	wilgeresc@wilgeresc.com	wilger.net

**Mention of a product or supply source does not constitute an endorsement of the products named or criticism of similar ones not mentioned. Mention of trade names does not constitute a guarantee or warranty of the products by the AFPMB, the Military Services, or the Department of Defense. Thanks to CDR (U. S. Navy Ret.) Joseph Conlon for supplying these last two lists.