PERFORMANCE OF HYDRAULIC AND ROTARY ATOMISERS FOR MOSQUITO SPRAYING

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Abstract

The performance of hydraulic flat fan and rotary cage and sleeve atomisers for aerial application of adul-ticides in mosquito control was assessed in a wind tunnel and spray chamber. Droplet size spectra were measured for different spray formulations of known physical properties, at different atomiser operational use conditions and wind tunnel air velocities. The droplet size measurements were made using a laser dif-fraction particle size analysis system. The sprays were studied using an Oxford Lasers spray visualisation system, which facilitated the interpretation of the atomisation data based on modes of liquid breakup.

The rotary atomisers were more capable of readily producing the optimum droplet size of 25 µm for this kind of application than were the hydraulic nozzles. Droplet size from the rotary atomisers could be con-trolled by changing the rotation rate either through adjustments to the pitch of the windmill blades or through changes in the voltage and current supplied to the electric motor. Droplet size decreased with higher rotation rates. Flow rate tended to reduce the rotation rate, which was the main reason for droplet size increasing as flow rates increased up to approximately 20 L/min. At higher flow rates, the mechanism of atomisation from the rotary atomisers changed from direct droplet formation and ligament breakup to sheet disintegration. With the coarser mesh rotary cage atomiser, some droplet formation was also by jet-on-wire shatter. With the 10, 20 and 40µm mesh porous screen rotary sleeve atomisers, the sprays were relatively narrow in droplet size ranges (low relative span) compared to similar sprays from the rotary cage atomisers. With the hydraulic nozzles, droplet size tended to decrease with higher pressure and wind speed, and greater nozzle angle to the airstream. The physical properties of the spray mixture affected droplet size, with finer sprays tending to be formed from lower surface tension conditions, due to less resis-tance occurring for spray formation.

Introduction

Optimum Droplet Size for Control of Mosquitoes

Many factors determine the performance of mosquito adulticide sprays. As with other types of pesticide application, droplet size is usually the most important of these factors [1]. Correlations of mortal-ity rates of adult mosquitoes in cages exposed to sprays suggested that the optimum droplet size is between 5 and 11 µm [2, 3, 4, 5]. Work with exposure of mosquitoes in the field suggests that the optimum droplet diameter is 5-22 µm [6, 7, 8]. A similar size range has been found to be optimal for mosquito control in wind tunnel studies [7]. Other researchers have determined the optimum droplet size for collection on mos-quitoes using scanning electron microscopy [9]. Insects were released into a chamber containing a polydisperse oil spray. The insects were collected and analyzed for the droplet sizes which they collected during flight. The study showed that 97% of the droplets collected by the mosquitoes were 2-16 µm.

Comparative droplet size work has shown that different measurement techniques can produce dif-ferent data for the same mosquito sprays [10]. Given this effect, droplet size classification systems have found utility for standardizing across measurement systems through the use of reference sprays [11, 12].

Equipment for Producing Adulticide Sprays

Given the need for droplets with diameter 5-25 µm for control of adult mosquitoes, careful atten-tion must be given to the selection and use of atomisers for aerial spraying. Some mosquito sprays are ap-plied with ground equipment such as foggers [13], however, the present paper discusses aerial applications.

In aerial adulticiding using hydraulic nozzles, pressures, nozzle angles and airstream velocities need to be high for production of small droplets. Wide fan angles and small orifice sizes also help optimize such applications. Aerial applications have also involved rotary cage and sleeve atomisers. These include Micronair and Beecomist models, although other manufacturers also exist. The use of rotary sleeve atom-isers is effective for mosquito control [14] with sprays in the 10 to 20 µm droplet diameter range [1].

A summary of factors affecting droplet size in aerial spray applications was given by [15 and 16].

Measurement of Droplet Size

Some researchers have measured droplet size for aerially-applied sprays using field measurement techniques with papers [17], rotary impaction samplers [18] or magnesium oxide coated slides [19]. A ma-jor limitation of such field sampling techniques is their tendency to under-estimate small droplets through poor collection efficiency and resolution. The use of wind tunnels for measuring sprays using non-intrusive laser sampling devices provides rapid sampling under controlled conditions. Good agreement has been found between droplet size spectra data measured in wind tunnels and on actual aircraft [20]. The use of wind tunnels for thousands of droplet size measurements by the Spray Drift Task Force (SDTF), a con-sortium of 39 agricultural chemical companies investigating factors affecting pesticide drift for regulatory requirements, was explained by Hewitt [21]. The SDTF studies included hydraulic and rotary atomisers. The SDTF used different sampling methods for hydraulic sprays than for rotary atomisers, due to the dif-ferent emission form from each application. While hydraulic nozzles were vertically traversed while con-tinually sampling to obtain a representative cross-section average droplet size distribution, multiple chordal measurements were compared with single centerline measurements with the atomiser and laser diffraction instrument laser beam central in the wind tunnel working section. The SDTF atomization and field studies have been described elsewhere [22, 23]. Teske [24] used the experimental atomization data collected by the SDTF and others to validate his theoretical assessments that the most appropriate approach to sampling rotary cage atomisers is through the use of centerline measurements. This approach has been included in a standard test method being finalized by the American Society for Testing and Materials (ASTM) for sam-pling liquid sprays with laser diffraction techniques [25]. This approach was also used in the present study.

Methods

The present study involved applications with flat fan nozzles and rotary cage and sleeve atomisers. These were sampled using full traverse and centerline measurements, respectively, in accordance with standard operating procedures used by the SDTF and also the appropriate ASTM standard [25]. All meas-urements were made in wind tunnels at New Mexico State University and the University of Queensland, Australia. These wind tunnels have been described by [21, 26].

A Malvern laser diffraction particle size analyzer was used to characterize the drop size spectra. All measurements were made using 600 or 800 mm focal length lenses which measured droplets in the size range 3 to1504 µm. Data and results were obtained using model independent analysis. All measurements were replicated with three measurements per treatment.

Spray solutions of Anvil® 10+10 (Clarke Mosquito Control Association, Roselle, IL) or tap water were displaced from spray tanks by compression.

The wind tunnel studies included airstream velocities representing those encountered in applica-tions with rotary wing (~80 mph) fixed-wing piston engine (~120 mph) and turbine engine (140 - 175 mph) powered aircraft. The major nozzle types used for commercial adulticide applications and tested in the wind tunnel studies included 80050, 8001, 8003, 8005 and 11001 flat fan nozzles (Spraying Systems Co., Wheaton, Illinois), a Micronair AU5000 rotary cage atomiser (Micron Sprayers Ltd., Bromyard, England) and Beecomist rotary sleeve atomisers with various screen sizes (Clarke Mosquito Control Association).

The rotary atomisers were operated at rotation rates between 11,200 and 17,500 rpm, measured us-ing optical and inductive pickup tachometers.

The flat fan nozzles were oriented at the typical mosquito adulticide spraying setting of 135° (i.e. 45° forward into the airstream), and the rotary atomisers were oriented straight back from the airstream.

Flat fan nozzle tests included spray pressures of 40 and 70 psi and wind speeds of 145 and 175 mph. Rotary atomiser tests included liquid flow rates of 0.66- 3.05 L/min and wind speeds of 80-175 mph.

Results and Discussion

Given the importance of droplets with diameter <25 µm for mosquito control, the results of the droplet size measurements are summarized with respect to the entire droplet size spectrum, the mean Dv0.5 and the spray volume contained in droplets with diameter below 24 µm (Vol<24 µm).

Flat fan nozzles

The application of water and Anvil at 40 psi pressure through 8001 and 8003 flat fan nozzles ori-ented at 135° into a 175 mph airstream (Figure 1) produced sprays with respective Dv0.5 values of 86 to 104 µm (water) and 55 to 73 µm (Anvil). The ability of the Anvil to produce finer sprays than the water proba-bly reflects the different physical properties, in particular lower dynamic surface tension of the Anvil com-pared to water. The production of finer sprays with smaller orifice diameters is consistent with previous work with hydraulic nozzles [22, 27, 28]. The influence of air shear causing the production of smaller droplets with higher airstream velocities in pesticide applications has been confirmed in previous work [29].

At a lower airstream velocity of 145 mph, the application of Anvil through a 11001 flat fan nozzle oriented at 135° to the airstream produced a similar Dv0.5 around 70 µm to the higher wind speed applica-tion (175 mph) with an 8001 nozzle. Previous research [22] has shown that narrower flat fan plume angles produce coarser sprays, so the present study shows that this can be offset (in the case of an 80° flat fan compared to a 110° flat fan) by increasing the air shear at the nozzle tip, for example by increasing the air-craft forward speed (in this case, from 145 to 175 mph). The range of Vol<24 µm values for applications of Anvil through these flat fan nozzles was 15 to 21 %.

Rotary Cage Atomiser

The Micronair AU5000 rotary cage atomiser produced finer sprays than the flat fan nozzles. However, where higher spray pressure with the flat fan nozzles produced higher flow rates and finer sprays with a given orifice diameter, greater flow rates caused the sprays from the rotary cage atomiser to become coarser. This is in agreement with previous studies, and reflects the fact that atomization from flat fan noz-zles is by a different mechanism than that from rotary atomisers. In flat fan nozzle atomization, liquid is discharged from the nozzle as a sheet which breaks down by the formation of perforations in the sheet. Atomization from rotary atomisers is usually by direct droplet or ligament formation. At high flow rates, the gauze of the rotary cage may become flooded, causing atomization to be through sheet breakup. Modes of atomization from different nozzle and atomisers have been discussed elsewhere [30, 31]. Dv0.5 values ranged from 27 to 57µm, depending on flow rate and rotation rate. The results are within range of expected findings from other studies. Van Vliet and Picot [32] tested a larger AU4000 atomiser with several fluids, flow rates and rotation rates, and obtained 40 to 60 % of the spray volume in droplets with diameter 15 to 55 µm at a wind tunnel speed around 110 mph. The higher wind speed in the present study provided 40% of the spray volume in this size range at a similar flow rate range of ~2 to 5 L/min. This is reasonable given that the atomiser was smaller for the present study, and the wind tunnel speed higher. The data do not agree well with field measurements of droplet size from an aerial application with AU5000 atomisers [17], where an AU5000 atomiser was operated at a wide range of rotation rates (not measured, but blades with unspecified length were operated at angles between 35 and 85°) with a flow rate of ~ 4 L/min. The flight speed was slower than that of the present wind tunnel tests (115 mph), and the tank mix comprised kerosene oil with carbaryl. The Dv0.5 values ranged from 99 to 273 µm. These values are larger than those from the present study for several reasons, the main factor being the different droplet sizing technique. Collection cards provide an intrusive deposition sampling technique which tends to under-estimate the smallest droplets in a spray.

In agreement with the present study findings, other researchers have observed that greater rotation rates produce finer sprays from rotary cage atomisers [29, 33-35]. At higher rotation rates, the droplets are effectively flung across the atomiser gauze with greater energy, producing smaller droplets. Wind tunnel studies with an AU5000 atomiser showed that this could produce smaller droplets than an 8004 flat fan nozzle. The rotary atomiser was used at flow rates between 2000 and 8000 mL/min and rotation rates of 4400 to 9500 rpm. In wind tunnel airstream velocities from 130 to 60 mph, the Dv0.5 values varied from 34 to 159 µm for a range of different tank mixes, which is within the droplet size ranges observed in the pre-sent study.

Rotary Sleeve Atomisers

Atomization through the Beecomist rotary sleeve atomisers was affected mainly by rotation rate, with higher rates producing finer sprays (Figure 2).

Wind speed and mesh size also had an effect on atomization (Figure 3). At higher wind speeds, the sprays became coarser, probably due to the effect of the wind on decreasing the spray plume angle and modifying the breakup length. A 1.5mm mesh size produced larger droplets and multi-model droplet size spectra, where the 20 and 40 µm porous high density polyethylene screens produced smaller droplets and mono-modal or bi-model size distributions. The 1.5mm mesh screen provided similar atomization behavior to the rotary cage atomisers.

The Beecomist 20 and 40 µm porous high density polyethylene screens produced Anvil sprays with Dv0.5 values of 25 to 35 µm, depending on the rotation rate, flow rate, airstream velocity and screen size. The corresponding Vol<24 µm range was 14 to 48 %. With the 1.5mm mesh screen, the respective Dv0.5 and Vol<24 µm ranges were 55 – 63 µm and 4 – 9 %.

Comparison of Flat Fan and Rotary Atomisers

The present study has shown that rotary cage and rotary screen atomisers provide the greatest po-tential for obtaining the droplet size of <25 µm required for optimum control of adult mosquitoes using aerial adulticiding. With a given atomiser, flow rate and flight speed scenario, droplet size can be con-trolled by changing the rotation rate of these rotary atomisers, with greater rotation rates producing smaller droplets.

Figure 4 compares the droplet size spectra produced by the flat fan nozzles and rotary atomisers. The rotary cage and 1.5mm screen rotary sleeve atomisers produced sprays that were bi- or multi-modal, while the flat fan and fine mesh screen size rotary sleeve atomisers produced sprays that were nominally mono-modal. The 20 and

40 µm porous high density polyethylene screen rotary sleeve atomisers produced the narrowest droplet size spectra.

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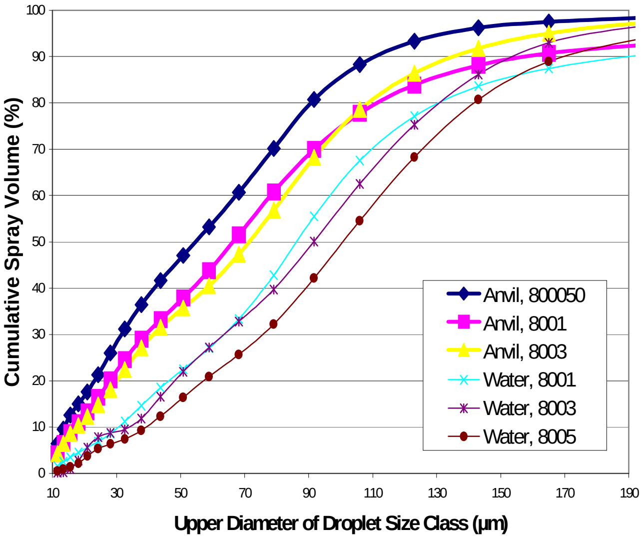

Fig. 1. Cumulative Volumetric Droplet Size Spectra for Application of Anvil 10+10 or Water at 40 psi Through Flat Fan Nozzles in 175 mph Airstream

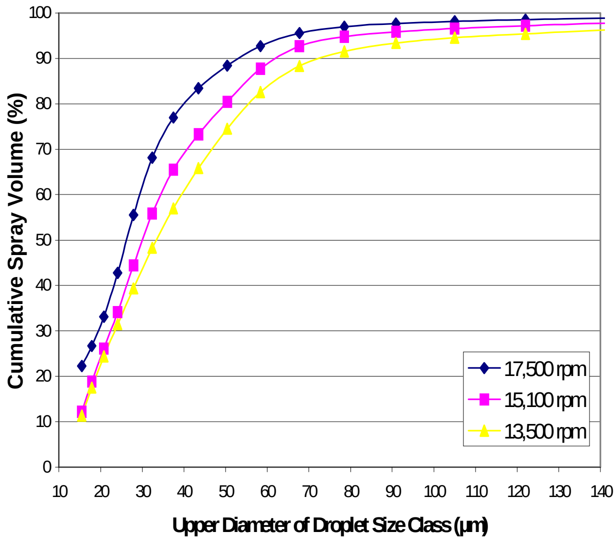

Fig. 2. Effect of Rotation Rate on Atomization of Anvil with Beecomist at 0.66 L/min Through 40µm Screen in 140 mph Air

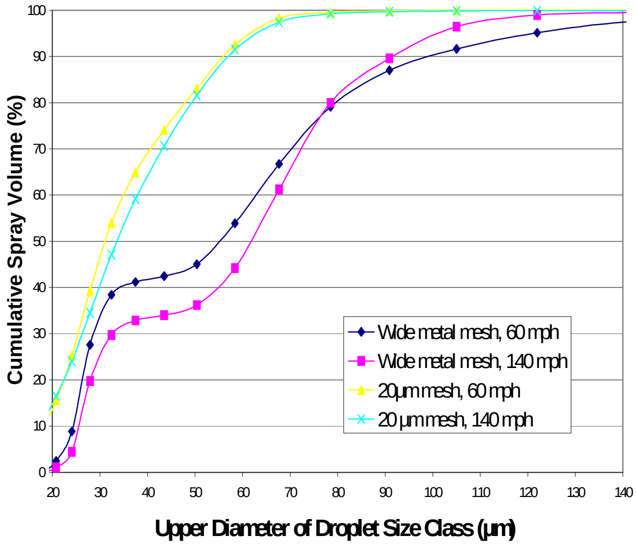

Fig. 3. Effect of Wind Speed on Atomization of Anvil Through Beecomist Atomizers, 1.3 L/min Flow Rate, 11200 rpm for Coarse Mesh and 12200 rpm for 20µm Screen

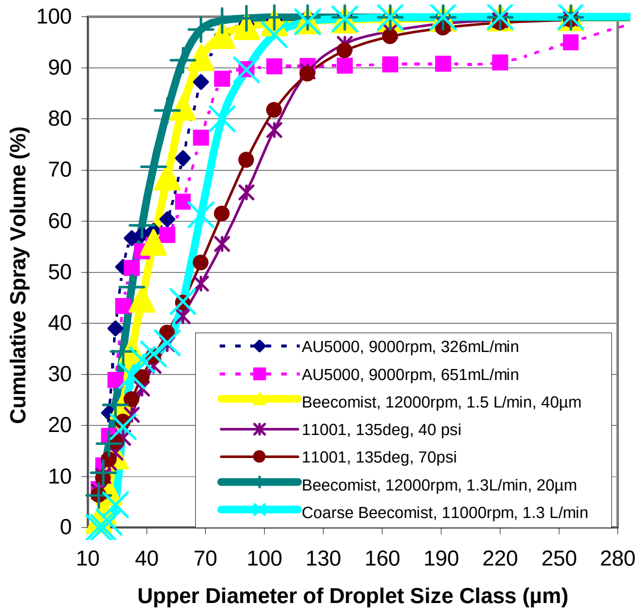

Fig. 4. Cumulative Volumetric Droplet Size Spectra for Anvil 10-10 Sprayed Through Different Atomizers in 145 mph Airstream