AEROSOL PENETRATION RELATIVE TO SENTINEL CAGE CONFIGURATION AND ORIENTATION[1]

BOBBIE L. BUNNER, FRANCO G. POSA, STEPHAN E. DOBSON, FLORENCE H. BROSKI AND LEWIS R. BOOBAR

U.S. Army Biomedical Research and Development Laboratory, Fort Detrick, Frederick, MD 21701-5010

ABSTRACT. Aerosol movement into 4 different sentinel cage configurations at 0°, 30° and 60° orientation relative to the aerosol flow in a wind tunnel was studied using a quartz crystal microbalance cascade impactor. The data suggest that a cylinder, screened on all sides, with the longitudinal axis perpendicular to the ground would provide a consistent cage profile to the wind regardless of wind direction changes and thereby reduce aerosol environment variability among cages.

INTRODUCTION

The influence that cage configuration and orientation to aerosolized pesticide may have on sentinel mosquito mortality is not fully known. The cage shape most widely used in adult mosquito field bioassays has been cylindrical. The cylinders have been constructed of cardboard (Walker et al. 1981), plastic (Bunner et al. 1987) and wire screen (Roberts 1982, 1984), with lengths ranging from 2.5 to 25 cm and diameters from 4.5 to 20 cm. The end facing the predominant wind direction is always of screen, while the opposite end may be screen (Bunner et al. 1987) or solid (Roberts 1982, Haile et al. 1984).

Pesticide concentration within the cage is influenced by placement within the test habitat (filtration by vegetation) (Haile et al. 1984), open area of screened surface (Boobar et al. 1988), type of screen material (Breeland 1970) and orientation of the cage to the wind (Rathburn et al. 1969). Breeland (1970) and Boobar et al. (1988) studied the effect of screen material on droplet size distribution. The latter investigators found that a smaller amount of open area in the screening (mesh size) resulted in a greater filtration of large droplets, and that metal screening filtered out greater numbers of large droplets than did nonconductive nylon screening.

The importance of mosquito cage orientation relative to the aerosol flow was demonstrated when Rathburn et al. (1969) oriented the longitudinal axis of cylindrical cages horizontally and vertically to the ground. After aerial application of insecticide, they reported higher mortality in the cages with the longitudinal axis of the cylinder horizontal to the ground and suggested that wind direction and drift are more important factors than settling in bioassay results with confined mosquitoes.

When using sentinel cages to monitor operational effectiveness, a screened surface is always positioned to face the predominant wind direction; and the aerosol is dispersed upwind of the area to be treated. However, applicators have to factor in the impact of gusts and eddies from different directions as well as major changes in wind direction (Johnstone et al. 1987). The purpose of this study was to assess the effect of cage

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Table 1. Chlorpyrifos aerosol size distribution collected in 4 different exposure cage configurations in a wind tunnel with a quartz crystal microbalance cascade impactor.[a]

Configuration	Mean ± SE droplet % in each sizing bin[b]				
	25 μm	12.5 μm	6.4 μm	3.2 μm	1.6 μm
Control (no cage)	7.1 ± 1.2 A	5.5 ± 0.9 A	9.1 ± 2.3 A	37.2 ± 2.3 A	41.1 ± 1.5 A
Solid plastic cylinder	1.4 ± 0.6 B	2.6 ± 0.5 A	3.0 ± 0.6 B	40.1 ± 5.7 A	53.0 ± 5.3 A
Screened plastic frame cylinder	4.5 ± 0.9 AB	2.8 ± 0.4 A	4.2 ± 0.7 AB	42.8 ± 7.1 A	45.7 ± 6.7 A
Rectangular solid plastic box	1.8 ± 0.5 B	3.2 ± 0.6 A	3.8 ± 0.4 AB	36.6 ± 5.2 A	54.6 ± 5.9 A
Rectangular screened plastic frame box	2.0 ± 0.9 B	5.6 ± 1.1 A	5.8 ± 1.1 AB	42.3 ± 6.9 A	44.3 ± 9.2 A

[a] Flow rate = 5 ml/sec; 10 sec sample collection; cage longitudinal axis parallel to aerosol flow.
[b] Means within a column followed by the same letter are not significantly different ($n = 5$, $\alpha = 0.05$; Scheffe's multiple comparison procedure; [SAS Institute 1985]).

configuration and wind direction on aerosol droplet dynamics within the cage.

MATERIALS AND METHODS

Tests were performed inside an ABS Model D-2 wind tunnel 14.6 cm inner diam × 91.4 cm long (American Biological Supply, Baltimore, MD). Air velocity was measured across the wind tunnel with a 6000-P Velometer (Alnor Instrument Co., Niles, IL) to verify a consistent and unobstructed airflow of 6.5 kph (4 mph). Aerosols were generated by shearing test liquids with pressurized air using a Bell and Gosset Duraire Vacuum Pump Model V-22O (ITT Fluid Handling Division, Monroe, LA) set at 6 psi. A liquid flow rate of 5 ml/sec was maintained with a Model RP-B Lab Pump (Fluid Metering, Inc., Oyster Bay, NY) for all tests. The test liquids, chlorpyrifos (Dursban 1.5 U.L.V. Mosquitocide, Clarke Outdoor Spraying Co., Roselle, IL) and reagent grade mineral oil (Fisher Scientific Co., Fair Lawn, NJ) were dispersed through nozzle orifice sizes of 0.114 cm for chlorpyrifos and 0.071 cm for mineral oil.

Four cage configurations were tested: a solid plastic cylinder (4.5 cm diam × 15 cm long) with screened ends; a plastic frame cylinder of the same dimensions with screened ends and sides; a 4.5 cm^2 × 12.5 cm long rectangular solid plastic box with screened ends; and a rectangular plastic frame box of the same dimensions with screened ends and sides. They were centered within the wind tunnel during testing. All screened surfaces on the cages were covered with nylon mesh tulle (8 × 11 mesh/cm^2) which was discarded after each replication.

Aerosol concentrations were measured with a Quartz Crystal Microbalance Cascade Impactor Model PC-2 (California Measurements, Inc., Sierra Madre, CA). The aerosol sample was drawn through a 33 cm Tygon® tube (0.138 cm inner diam) at 240 ml/min from the sampling point to the sensing stack where aerosol droplets were segregated into separate bins. The size range of each bin is determined by the 50% probability of capture of droplets of that particular size based on a particle density of 2 g/cm^3 (Dp50). The bin sizes range from 0.05 to 25 μm; however, for the purposes of this study, only data in the size ranges above 1 μm (5 bins) were reported.

Samples of the test aerosols were taken for 10 sec each and replicated 5 times for each of the cage configurations oriented with the longitudinal axis of the cage at 0° (parallel), 30° and 60° to the aerosol stream for cylindrical cages (Fig. 1), and for controls (no cage). The quartz crystal microbalance probe was centered within the cages 60 cm downwind of the dispersal nozzle during the sampling period.

To compare droplet frequency distribution (Table 1), the volume of aerosol in each bin was mathematically converted into the number of droplets of that specific size range collected. In Table 2, the total mass of chlorpyrifos or mineral oil per unit volume is calculated from all droplets counted in the 5 bins (1–25 μm). Data were analyzed using the SAS® General Linear Models Procedure for analysis of variance to determine effects. Means were compared using Duncan's multiple range procedure following a significant F-test or by Scheffe's multiple comparison procedure.

RESULTS AND DISCUSSION

Data in Table 1 generally supports the hypothesis that cage configuration has little impact on aerosol entry when the screened end is oriented directly into the aerosol stream. It also suggests that, regardless of cage configuration, larger droplets are somewhat inhibited from entry in support of Khoo and Sutherland (1983) and Boobar et al. (1988), who described the filtering effect of screens on large droplets.

Table 2 shows the changes in concentrations of chlorpyrifos and mineral oil aerosol droplets in both screened and solid cages with increasing angles relative to the aerosol stream. The decreases in mean concentration relative to controls (no cage) for the screened cylindrical cages at 0° (22.3, 36.0%) were not statistically different ($P < 0.05$) from the decreases for the solid cylindrical cages at 0° (32.1, 28.8%). This shows that additional aerosol was not entering the cages through the side screens on the screened cages. Figure 1, row 1, depicts the cage profile presented to the aerosol flow during testing and shows graphically why both cages allowed similar concentrations to enter. There were significant differences ($P < 0.05$) in the concentrations of mineral oil and chlorpyrifos entering the cages when the angle, and thereby the profile (Fig. 1), was changed from 0° to 30° and 60°. In both screened and solid cylindrical cages, considerably less aerosol entered the cage through the front face (32% for mineral oil and 47% for chlorpyrifos, as determined by subtracting percent change at 0° from 30° for the solid cages).

Stagnation points form at the entrance of tubes angled to the aerosol flow, creating a velocity gradient at the entry point that will reduce interior velocity (Tritton 1977). This was demonstrated by the data in Table 2 with a significant decrease in droplets per unit volume within the solid cages as the angle of aerosol flow in relation to the longitudinal axis of the cage increased from 0° to 30° ($P < 0.05$).

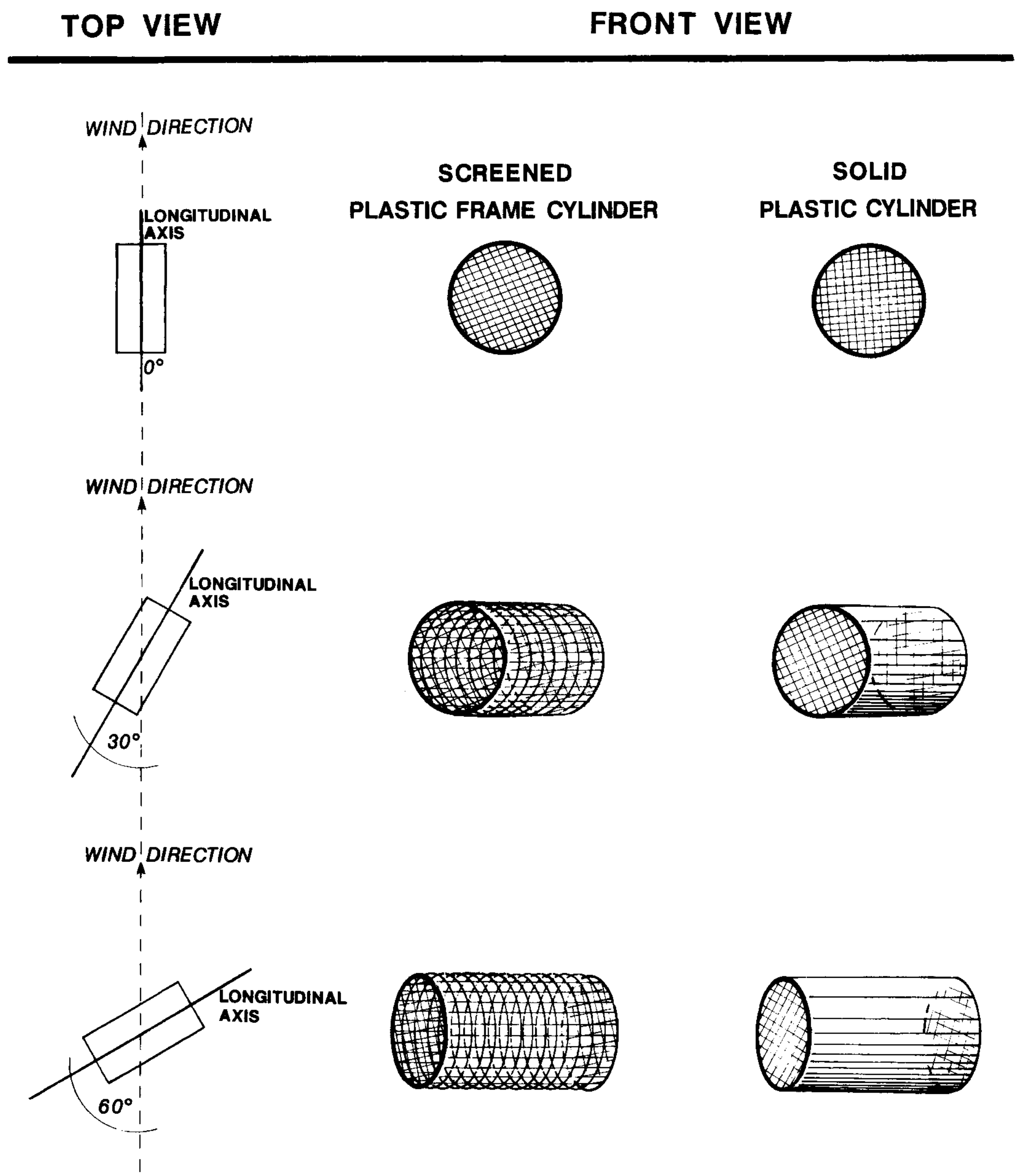

Fig. 1. Profiles of screened and solid sentinel mosquito cages when their longitudinal axis is angled 0°, 30° and 60° from the wind.

Screened, cylindrical cages create different conditions than the impermeable solid cylindrical cages as the angle to the wind changes from 0°. Table 2 shows the concentration between 0° and 30° in the screened cage did not change despite 32–47% reduction in aerosol entering through the screened end facing the wind. The mesh threads of the side screening exposed the edge of the fabric to the direction of flow and continued to act as a partial barrier.

As the angle to the aerosol flow increased to 60°, the side wall screens were approaching perpendicular to the aerosol flow (Fig. 1), and the aerosol concentration per unit volume within the cage increased from the 30° (Table 2) (Duncan's $P < 0.05$). As the angle increased from 30° to 60°, the open area of the mesh increased. At 60°, the mesh presented 86% of the open area toward the direction of aerosol flow; and as the circular (elliptical presentation to the flow at

Table 2. Mean aerosol concentration (mg/m^3)[a] and percent change from control of chlorpyrifos and mineral oil in screened and solid cylinders in a wind tunnel with increasing angle of orientation to air stream.[b]

Orientation	Screened mg/m^3 [c] $\bar{x} \pm$ SE	Screened % change	Solid mg/m^3 [c] $\bar{x} \pm$ SE	Solid % change
Chlorpyrifos				
Control (no cage)	3.09 ± 0.110 A	—	3.09 ± 0.110 A	—
0° angle	2.39 ± 0.273 BC	22.3	2.09 ± 0.156 B	32.1
30° angle	2.15 ± 0.173 C	29.6	0.66 ± 0.039 C	78.6
60° angle	2.73 ± 0.103 AB	11.3	0.86 ± 0.184 C	72.1
Mineral oil				
Control (no cage)	4.35 ± 0.182 A	—	4.35 ± 0.182 A	—
0° angle	2.79 ± 0.186 B	36.0	3.09 ± 0.069 B	28.8
30° angle	2.97 ± 0.303 B	31.5	1.68 ± 0.158 C	60.8
60° angle	3.75 ± 0.139 A	12.9	1.66 ± 0.091 C	61.5

[a] Total concentration for the 5 bins (1–25 μm droplets).
[b] Flow rate = 5 ml/sec; 10 sec sample collections.
[c] Means within a column followed by the same letter are not significantly different ($n = 5$; $\alpha = 0.05$; Duncan's multiple range test; [SAS Institute 1985]).

this angle) front face separated the flow, aerosol droplets were now able to enter the cages through both the front face and the screened sides. As the data show, this created a close approximation of the "no cage" condition (chlorpyrifos 11.3%, mineral oil 12.9% change relative to control).

The data show that, as the wind direction changes, the aerosol concentration within cylindrical cages is altered with each new profile. If a sentinel cage configuration such as a screened sphere were used, which always presents the same amount of open area in the mesh screening to the wind regardless of directional changes, then between-cage variability would be reduced. The mechanics of insect transfer from a spherical cage make it a less than ideal choice for sentinel cage shape. It is proposed that a standardized cylindrical cage screened on all sides with the longitudinal axis oriented perpendicular to the ground gives the closest practical approximation to a screened sphere. A vertically oriented cylinder presents the same surface to wind from any horizontal direction, and wind directional changes horizontal to the ground have a greater impact on bioassay results than settling (Rathburn et al. 1969). Cylindrical cages allow for rapid transfer of mosquitoes, thus reducing the impact of nonaerosol contamination of bioassay specimens resulting from contact with screening (Bunner et al. 1989).

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