# COMPARISONS OF THERMAL AND NONTHERMAL AEROSOLS OF MALATHION, FENTHION, AND NALED FOR CONTROL OF STABLE FLIES AND SALT-MARSH MOSQUITOES

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Lofgren *et al,* (1966) obtained high mortalities of caged *Culex tritaeniorhynchus* Giles and *C. quinquefasciatus* Say by dispersing water emulsions of several insecticides from a nonthermal aerosol generator. Their results were somewhat similar to those obtained by Gahan *et al.* (1965), who used a thermal aerosol generator to disperse fuel oil solutions of the same insecticides against the same two species of mosquitoes. However, no results of direct comparisons between thermal and nonthermal aerosols for control of flying insects have been reported. The primary objective of this study was to obtain comparative data pertaining to both types of aerosols for control of stable flies [*Stomoxys calcitrans* (L.)] and salt-marsh mosquitoes [*Aedes taeniorhynchus* (Wiedemann) and *A. sollicitans* (Walker)].

The thermal aerosol generator used in this study was a Leco model 120 [1] and the nonthermal aerosol generator was a Curtis model 55,000 [1] designed and developed by the U. S. Army Engineers Research and Development Laboratories, Fort Belvoir, Virginia (Morrill and Wesley, 1955 and Edmunds *et al.,* 1958). Both generators were calibrated to deliver 40 gallons of liquid per hour and the thermal generator was operated at a temperature of 850° F.

The insecticides used were malathion, fenthion, and naled. Fuel oil solutions of these insecticides were applied with the thermal generator, whereas both fuel oil solutions and water emulsions were applied with the nonthermal generator. Fuel oil solutions were prepared from technical malathion or from oil-soluble concentrates containing 8 pounds of fenthion or 14 pounds of naled per gallon. A sludge inhibitor (mixed amide amine oleate from modified fatty acids and polyamines) was used in the fuel oil formulations at rates of 0.5 to 1 percent as needed to retard the formation of precipitates. Emulsifiable concentrates containing 5, 4, and 8 pounds per gallon of malathion, fenthion, and naled, respectively, were used to prepare the water emulsions. The emulsions were always applied the same day they were prepared.

Tests with Caged Stable Flies and Mosquitoes. The experimental plots, located at an airport near Gainesville, Florida, were fairly level and open. The stable flies used in these tests were from a laboratory colony established with larvae

[1] Mention of proprietary products does not necessarily imply endorsement by the U.S.D.A.

collected at a livestock farm near Panama City, Florida. Specimens of *A. taeniorhynchus* were from a laboratory colony started by Davis (1958). All insects were 2–7 days old when tested. They were exposed in cylindrical cages made of 16-mesh screen wire. The cages used for stable flies were 3 inches in diameter x 8 inches long and those employed for mosquitoes were 1.75 inches in diameter x 5.5 inches long. Cages of stable flies (four per test) were placed on two rows of stakes 125 feet apart at distances of 125 and 250 feet downwind from and perpendicular to a line over which the truck-mounted aerosol generators passed. The cages of mosquitoes (four per test) were placed on two rows of stakes 150 feet apart at distances of 150 and 300 feet from the aerosol discharge line. All cages were placed at a height of 5 feet above the ground.

The aerosol generators were always moved at a speed of 5 m.p.h. In each test, the aerosol was allowed to drift completely across the experimental plot before the cages were removed from the stakes. Stable flies were returned to the laboratory after each series of tests (the tests lasted 1–2 hours) and transferred to clean screen cages in a cold room (34° F). Immediately after each exposure, mosquitoes were blown into plastic tubes lined with clean paper. Except during exposure, all insects were protected in the field by keeping them in insulated chests containing ice in cans. Stable flies were provided a 10 percent honey-water solution for a 24-hour holding period and mosquitoes were provided 10 percent sugar-water solution for an 18-hour holding period in a room maintained at 80° F. Mortality counts were made at the end of the holding periods. Probit analysis,[2] as described by Finney (1952), was used to calculate the $LC_{90}$'s for the various aerosols.

[2] Data were processed according to a program developed by R. J. Daum, Biometrical Services, U.S.D.A., for the IBM 1620 computer.

Control groups of stable flies and mosquitoes were exposed to thermal aerosols of fuel oil with no insecticide and nonthermal aerosols of fuel oil and water with no insecticide to check natural mortality encountered during these tests. Additional checks were also made by observing untreated insects in the laboratory.

Tests with stable flies were conducted on 16 different days at times ranging from 1 to 4 p.m. Air temperatures ranged from 71° to 90° F, with an average of about 79° F. Wind speeds ranged from 2 to 12 m.p.h. and averaged about 6 miles per hour. Tests with mosquitoes were conducted on 13 different evenings at times ranging from 6:30 to 9 p.m. Air temperatures ranged from 73° to 85° F and averaged about 80° F. Wind speeds ranged from 2 to 10 m.p.h. and averaged about 4 miles per hour. All tests were conducted during inversions. From two to five tests with four cages of insects per test were run with various concentrations of each insecticide.

The results of the tests with stable flies are presented in table 1. The mortality percentages are averages of results obtained at exposure distances of 125 and 250 feet. The results with male and female stable flies were averaged together since there was no substantial difference between the susceptibility of the sexes to the three insecticides. Malathion was tested at concentrations of 5, 10, and 20 percent. Mortalities obtained with the nonthermal aerosol of malathion diluted in water were higher than those obtained with the other aerosols; however, the differences were not extremely large. Fenthion and naled were tested at concentrations ranging from 0.31 to 5 percent. With both compounds, differences in mortality between the types of aerosols were slight, and none of the differences in the $LC_{90}$'s were statistically significant at the 95-percent level of probability. The averages of all results, regardless of the type of aerosol used, indicated $LC_{90}$'s of 2.1 and 1.4 percent for fenthion and naled, respectively.

The results of the tests with caged

TABLE 1.—Mortality of caged adult stable flies exposed to thermal and nonthermal aerosols of malathion, fenthion, and naled.

| Type of aerosol | Diluent | Percent mortality at indicated concentration (%)[a] | | | | | | | $LC_{90}$ (%) | 95% confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 10 | 5 | 2.5 | 1.25 | 0.62 | 0.31 | | |
| | | | | | Malathion | | | | | |
| Thermal | Fuel oil | 69 | 62 | 39 | .. | .. | .. | .. | >20 | ......... |
| Nonthermal | Fuel oil | 83 | 46 | 31 | .. | .. | .. | .. | >20 | ......... |
| | Water | 92 | 70 | 40 | .. | .. | .. | .. | 18.4 | 13.2–45.6 |
| | | | | | Fenthion | | | | | |
| Thermal | Fuel oil | .. | .. | 97 | 94 | 82 | 44 | 46 | 2.3 | 1.7–3.9 |
| Nonthermal | Fuel oil | .. | .. | .. | 96 | 82 | 59 | 39 | 1.9 | 1.3–3.8 |
| | Water | .. | .. | 99 | 89 | 80 | 62 | 26 | 2.1 | 1.5–4.4 |
| | | | | | Naled | | | | | |
| Thermal | Fuel oil | .. | .. | 99 | 97 | 89 | 61 | 34 | 1.5 | 1.2–1.8 |
| Nonthermal | Fuel oil | .. | .. | 100 | 94 | 92 | 52 | 33 | 1.6 | 1.2–2.5 |
| | Water | .. | .. | 100 | 100 | 97 | 64 | 30 | 1 | .8–1.3 |

[a] Corrected by Abott's formula; average of male and female stable flies exposed at distances of 125 and 250 feet.

TABLE 2.—Mortality of caged female *Aedes taeniorhynchus* exposed to thermal and nonthermal aerosols of malathion, fenthion, and naled.

| Type of aerosol | Diluent | Percent mortality at indicated concentration (%)[a] | | | | | | | | $LC_{90}$ (%) | 95% confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 4 | 2 | 1.5 | 1 | 0.5 | 0.25 | 0.1 | | |
| | | | | | Malathion | | | | | | |
| Thermal | Fuel oil | 99 | 97 | 88 | .. | 73 | 11 | .. | .. | 2.2 | 1.6–4 |
| Nonthermal | Fuel oil | 98 | 92 | 79 | .. | 69 | 18 | .. | .. | 3.1 | 2.2–5.4 |
| | Water | 94 | 93 | 82 | .. | 58 | 13 | .. | .. | 3.2 | 2.3–5.6 |
| | | | | | Fenthion | | | | | | |
| Thermal | Fuel oil | .. | .. | .. | 98 | 94 | 72 | 50 | 28 | .92 | .67–1.7 |
| Nonthermal | Fuel oil | .. | .. | .. | 98 | 97 | 67 | 67 | 51 | .96 | .56–6.1 |
| | Water | .. | .. | .. | 95 | 98 | 66 | 52 | 25 | .98 | .69–2 |
| | | | | | Naled | | | | | | |
| Thermal | Fuel oil | .. | .. | 96 | 89 | 82 | 64 | 45 | .. | 1.5 | .96–5.5 |
| Nonthermal | Fuel oil | .. | .. | 96 | 93 | 92 | 57 | 68 | .. | 1.3 | .87–3.1 |
| | Water | .. | .. | 93 | 94 | 89 | 38 | 24 | .. | 1.3 | 1–1.9 |

[a] Corrected by Abbott's formula; average of mosquitoes exposed at 150 and 300 feet.

females of *A. taeniorhynchus* are given in table 2. The mortality percentages are averages of results obtained at 150 and 300 feet. Malathion, fenthion, and naled were tested at concentrations ranging from 0.5 to 8 percent, 0.1 to 1.5 percent, and 0.25 to 2 percent, respectively. With all three compounds, differences in mortality between the two types of aerosol used were small, and none of the differences in the $LC_{90}$'s were significant at the 95-percent level of probability. The averages of all results, regardless of the type of aerosol used, indicated $LC_{90}$'s of 2.8, 0.95, and 1.4 percent for malathion, fenthion, and naled, respectively.

TESTS WITH NATURAL POPULATIONS OF SALT-MARSH MOSQUITOES. Tests with natural populations of salt-marsh mosquitoes (*A. taeniorhynchus* and *A. sollicitans*) were conducted at Scottsmore (Brevard County), Cedar Key (Levy County), and St. James City (Lee County), Florida. At Scottsmore, the experimental plots were sections of citrus groves, whereas at the other two locations they consisted of moderately to heavily wooded sections of land partially covered with undergrowth. The predominant species on all the plots was *A. taeniorhynchus*.

Naled was tested at a concentration of 1.5 percent in thermal and nonthermal aerosols at all three locations. All malathion tests were conducted at Cedar Key with a 6 percent concentration. The applications were made at 5 miles per hour for a distance of approximately ¼ mile along roads that would allow the wind to drift the aerosols across the plots. The quantity of insecticide was measured before and after each test to confirm the discharge rate of each aerosol generator. Plots were selected on the basis of uniformity in density and type of vegetation and abundance of mosquitoes; however, the treatments were rotated from one test to another to minimize any differences that might have existed in the plots.

The relative abundance of mosquitoes in each plot was sampled by counting the number landing per man per minute on two observers at six stations. In the citrus groves, counting stations were located in two rows near the center of the plots at distances of approximately 100, 150, and 200 feet from the roads along which the aerosols were discharged. The rows were 150 feet apart. In the wooded plots at Cedar Key and St. James City, the stations were about 75–200 feet from the roads where the insecticides were discharged and 50–100 feet apart. Pretreatment counts were made 1–24 hours before treatment. Counts were made 1–3 hours and 15–24 hours after treatments with naled. Counts were made 3 and 24 hours after treatments with malathion.

In three of the tests with 1.5 percent naled, caged mosquitoes were exposed in the plots to compare their mortality with reductions obtained in the natural populations. Females of *A. taeniorhynchus* were collected in areas adjacent to the plots with battery-powered aspirators and transferred to 16-mesh screen wire cages. The cages were placed 100–150 feet from the aerosol discharge roads in the vicinity of the counting stations. Three cages of approximately 10 mosquitoes each were exposed in each plot. Two were placed at 6 feet and one at 2 feet above the ground. Mortality counts were made at about the same time as the counts of the natural populations in the plots (1–3 hours after treatments).

The tests at Scottsmore and Cedar Key were conducted in the evening between 5:30 and 7 p.m. The tests at St. James City were conducted in the morning between 7 and 8 a.m. Air temperatures ranged from 81° to 90° F, and averaged about 86° F. Wind speeds ranged from $<2$ to 8 m.p.h. and averaged about 2.5 m.p.h. All of the tests were conducted during inversions.

The control of the natural population obtained in the plots is shown in table 3. Thermal aerosols of 6 percent malathion in fuel oil gave 83 percent reduction in 3 hours, whereas nonthermal aerosols of 6 percent malathion in water gave 86 percent reduction at the same interval of time. Plots which received no insecticide had an average reduction of 37 percent at 3 hours. Counts at the 24-hour interval

Table 3.—Control of natural populations of salt-marsh mosquitoes with thermal and nonthermal aerosols of malathion and naled.

| Type of aerosol | Diluent | No. of replications | Pretreatment count (man/min.) | Percent reduction at indicated interval after treatment[a] 1–3 hr. Average | 1–3 hr. Range | 15–24 hr. Average |
|---|---|---|---|---|---|---|
| | | | Malathion (6%) | | | |
| Thermal | Fuel oil | 2 | 7 | 83[b] | 81–84 | 35 |
| Nonthermal | Water | 2 | 7 | 86[b] | 86–86 | 20 |
| None | .. | 2 | 10 | 37[b] | ..... | +24 |
| | | | Naled (1.5%) | | | |
| Thermal | Fuel oil | 8 | 23 | 77 | 63–97 | +17[c] |
| Nonthermal | Fuel oil | 4 | 34 | 82 | 69–90 | +37[c] |
| Nonthermal | Water | 7 | 11 | 79 | 63–94 | 41 |
| None | .. | 8 | 24 | 26 | ..... | +23 |

[a] +indicates percent increase.
[b] 3 hour counts only.
[c] Treatments included in one test where reinfestation was extremely high at 24 hours.

showed that plots treated with both thermal and nonthermal aerosols were reinfested.

Thermal and nonthermal aerosols of 1.5 percent naled produced reductions of 77–82 percent at intervals of 1–3 hours after applications. Plots receiving no insecticide had an average reduction of 26 percent at the same intervals of time. Both types of aerosols showed reinfestation within 15–24 hours after application. In one series of tests with thermal and nonthermal aerosols containing 1.5 percent naled in fuel oil, the reinfestation was extremely high at 24 hours. Nonthermal aerosols of 1.5 percent naled in water were not included in this series of tests.

The results of the comparison between caged and free-flying salt-marsh mosquitoes exposed to naled are presented in table 4. When thermal aerosols in fuel oil were used, reductions averaged 75 percent with free-flying mosquitoes and mortality averaged 70 percent with caged mosquitoes within 1–3 hours after application. Nonthermal aerosols in water produced a reduction of 62 percent of the free-flying mosquitoes and mortality of 76 percent of caged mosquitoes at the same intervals of time.

Discussion. The mortalities of caged stable flies exposed to aerosols of malathion, fenthion, and naled were somewhat higher at comparable concentrations than those obtained in previous tests (Mount *et al.*, in press); however, these differences can be accounted for by the more favorable climatic conditions at the time the aerosols were applied. These results appear to eliminate malathion as an aerosol for prac-

Table 4.—Comparison of results obtained with free-flying and caged salt-marsh mosquitoes, 1–3 hours after exposure to thermal and nonthermal aerosols of 1.5 percent naled. (Data corrected by Abbott's formula.)

| Mosquitoes | Thermal aerosols[a] | Nonthermal aerosols[b] | Average |
|---|---|---|---|
| Free-flying (% reduction) | 75 | 62 | 68.5 |
| Caged (% mortality) | 70 | 76 | 73 |

[a] 2 replications.
[b] 3 replications.

tical control of adult stable flies, whereas both fenthion and naled appear very promising.

The results of the tests against caged females of *A. taeniorhynchus* agree with those obtained under similar conditions by Rathburn *et al.* (1964) and Rathburn and Rogers (1961). Fenthion was the outstanding compound in these tests. This result was expected since fenthion was more toxic than naled or malathion in wind-tunnel tests reported by Davis and Gahan (1961). Malathion and fenthion were considerably more effective against females of *A. taeniorhynchus* than against stable flies. On the other hand, the $LC_{90}$'s for naled were identical for both species.

The results with natural populations of salt-marsh mosquitoes confirm the data obtained with caged insects and indicate there were no significant differences between the reductions produced by the different types of aerosols. However, at comparable concentrations, the reductions of natural populations were not as high as mortalities of caged mosquitoes exposed on open plots (table 2). This result was expected since the tests with natural populations were conducted on dense, wooded plots. Mortalities of caged mosquitoes exposed on the wooded plots (table 4) were about the same as reductions of free-flying mosquitoes.

SUMMARY. Tests with caged stable flies, *Stomoxys calcitrans* (L.), caged female *Aedes taeniorhynchus* (Wiedemann), and natural populations of salt-marsh mosquitoes, *A. taeniorhynchus* and *A. sollicitans* (Walker), demonstrated that thermal and nonthermal aerosols were about equally effective when malathion, fenthion, and naled were used as toxicants. Water was equal to fuel oil as a diluent for insecticides dispersed as nonthermal aerosols. In wooded plots treated with thermal and nonthermal aerosols of 1.5 percent naled, mortalities of mosquitoes exposed in 16-mesh screen wire cages were about the same as reductions of free-flying mosquitoes.

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