AERIAL APPLICATION OF A CHEMICAL FOG FOR THE CONTROL OF MOSQUITO LARVAE AND ADULTS [1]

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With the advent of ultra low volume (ULV) aerial application of insecticides, mosquito control has taken another stride forward. Although ULV applications have proven effective, the method does have some disadvantages. Two of these are the inability by this method, to (1) penetrate heavy foliage, and (2) the limited time for application. Very seldom is the weather condition correct for more than one or two hours of application at a time. With this in mind, a new method of insecticide application, a cold-chemical fog, was tested to see if these disadvantages could be overcome.

The use of silicon tetrachloride ($SiCl_4$) with water vapor and ammonia to produce a cold fog was first reported in this country by Stokes (1967) and tested in Michigan against mosquitoes by Stevens *et al.* (1967).[3] This method has been used for insect control in Argentina for several years (Pinto 1967).[4] The use of silicon and other elements such as tin and

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[1] The investigation reported in this paper (No. 68-7-18) is in connection with a project of the Kentucky Agricultural Experiment Station and is published with approval of the Director.

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titanium to form tetra-chlorides that hydrolyze almost completely in moist air to form a fog or mist is not new. It was practiced extensively during World War I to hide the movements of vessels and troops (Dull, 1931). The adaptation of this as a carrier for insecticides, however, is new.

DESCRIPTION OF CHEMICAL REACTION. According to Pinto and Livaudais (1967)[5] the basic fog vehicle (without insecticide) is produced by the simultaneous interaction of $SiCl_4$ with water vapor and ammonia. There are two primary steps in this reaction:

$$\text{Step 1. } SiCl_4 + 2H_2O \text{ (as vapor)} \longrightarrow SiO_{2(S)} \text{(Hydrated} + 4\ HCl$$

$$\text{Step 2. } 4HCl + 4NH_3 \text{ (gas)} \longrightarrow 4NH_4Cl_{(S)}$$

Because these two steps take place simultaneously the reaction could simply be stated as:

$$SiCl_4 + 4NH_3 + 2H_2O \longrightarrow SiO_{2(S)} + 4NH_4Cl_{(S)}$$

The mechanical manner of producing the reaction leads to most of it taking place in the vapor phase, thus producing a fog of finely divided, hydrated SiO_2 and NH_4Cl particles. According to the inventor of the process these particles are in the range of 5–10 microns in diameter.[4] The major weight constituent of the fog is NH_4Cl. It represents 78 percent by weight of the fog, and the SiO_2 represents 22 percent. However, since the SiO_2 is probably in the form of hydrated silica (simplest form is H_2SiO_3), the particulate weights are in the ratio of 3 of NH_4Cl: 1 of SiO_2.

In actual operation, a compatible or miscible insecticide is mixed with $SiCl_4$ in the liquid state. As the reaction takes place, the insecticide is bound to the particles of NH_4Cl and SiO_2 by occlusion, absorption and surface adhesion.

A larger portion of the insecticide is probably carried by the silica portion of the fog than by the NH_4Cl, although the weights are in the opposite ratio. The transport vehicle for the insecticide is probably the fog particles, rather than a mist or vapor of the insecticide itself.

It is theorized that there is an immediate release of insecticide from the rapidly soluble NH_4Cl particles and that the insecticide contained on or within the SiO_2 particles is released much more slowly, giving some residual effect.

MATERIALS AND METHODS. A Piper Super Cub airplane was adapted for applying the cold-chemical fog, as shown in Fig. 1. Three 5-gallon stainless steel soft-drink containers were connected by copper lines to make one 15-gallon unit. These containers held the 5 percent ammonia water. Another 5-gallon stainless steel tank was used for holding the $SiCl_4$ insecticide mixture. Each separate unit was equipped for pressurizing by use of a quick connecting joint. Nitrogen was used for pressurizing the ammonia water and carbon dioxide was used to pressurize the $SiCl_4$ insecticide mixture. Each unit was equipped with a 12-volt electric solenoid valve on the outlet side of the spray line. The outlet lines consisted of ⅜-inch polyethylene tubing that was secured to the right wing structure of the plane. The ammonia line was connected to a ring-shaped nozzle made of the same tubing. The $SiCl_4$ mixture was connected to a cone nozzle located within the ring-shaped nozzle. Both nozzles were secured to the center of a large venturi (10 in. by 18 in.) attached to the wing structure (Fig. 1). As the two mixtures were released from the nozzles they combined in the atmosphere to form the reaction.

The CO_2 cylinder and the N_2 cylinder,

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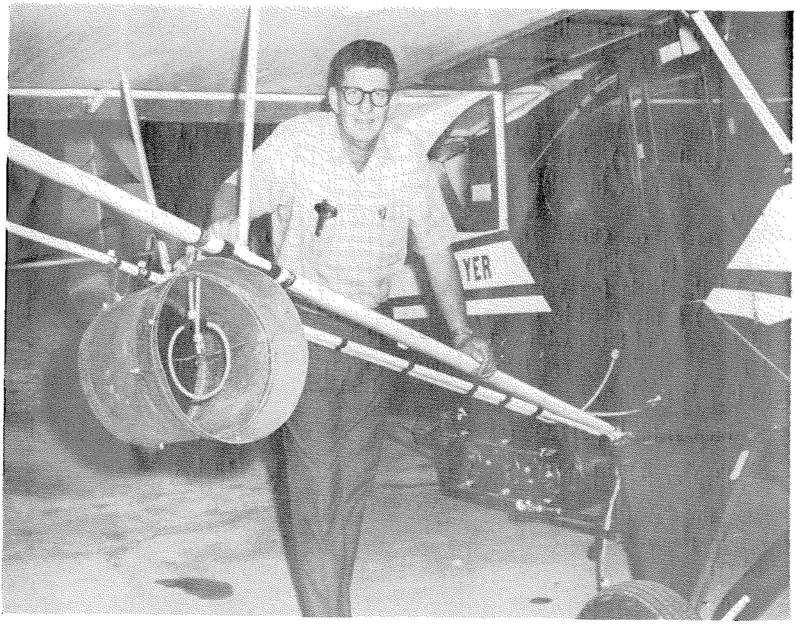

FIG. 1.—Spray tanks and spray lines attached to fuselage and venturi and spray nozzles attached to plane wing structure. Center nozzles carried $SiCl_4$ mixture. Outer nozzle (ring) carried ammonia water.

both small enough to fit upright behind the second seat of the plane, were controlled by pressure regulator valves. Both solenoid valves were operated by one switch located on the instrument panel of the plane. The author made all pressure adjustments during the application, whereas the pilot controlled the actual application.

For each compound tested, calibration was done on the ground. The ratio of ammonia water to $SiCl_4$ mixture was 3:1, and the total volume of the solution displaced through the nozzle was 4 gal./minute. The applications were made over areas of approximately 100 acres each at a speed of 80 m.p.h. and at an altitude of 60–100 feet, depending upon the terrain and vegetative growth.

Fig. 2 shows the aerial dispersion of cold-chemical fog. Figs. 3 and 4 show the dispersion of the fog in the vegetation. This application was made during the late afternoon, and the conditions were considered ideal for the test, i.e., the temperature was 75° F., relative humidity above 90 percent, and the wind less than 3 m.p.h.

Test 1. On September 12, 1967, at 1730 hours, fenthion was applied over a grass airplane runway. Ten *A. aegypti* second and third instar larvae were placed in 32-oz. wax-coated cottage cheese cartons. A series of these cartons, without covers, was placed every 100 feet for 1,000 feet, in a line at right angles to the flight of the airplane from which the fog was dispersed. The cartons were replicated 5 times at 65-foot intervals. Ten covered cartons were placed in the center of the treated area at the distance already mentioned and served as untreated checks.

The wind speed was approximately 2 m.p.h., relative humidity 100 percent and the temperature was 72° F. Fenthion (8 lb./gal.) was mixed with $SiCl_4$ at the ratio of 1:1. Based upon a 450-foot swath width, this was applied at the rate

FIG. 2.—View of cold-chemical fog being applied by plane.

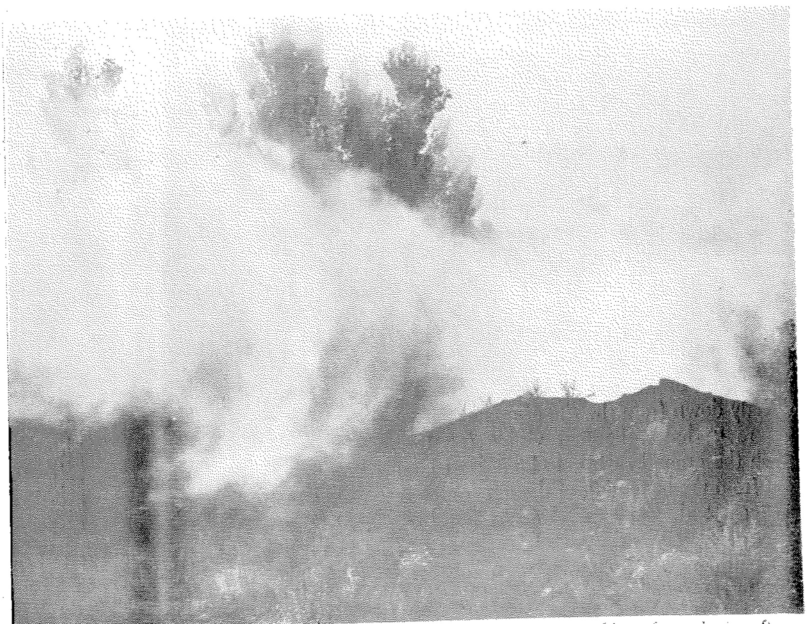

FIG. 3.—Dispersion of the cold-chemical fog among vegetative growth within a few minutes after application.

FIG. 4.—Dispersion of the cold-chemical fog among vegetative growth several minutes after application.

of 0.05 lb. per acre. The purpose of this test was two-fold: (1) to determine the larvicidal efficacy of the chemical-fog method; and (2) to determine an effective swath width to be used in future tests.

RESULTS AND DISCUSSION. Table 1 shows the results of fenthion as a larvicide when applied in a cold-chemical fog and the swath width obtained under these conditions. We were surprised to obtain 100 percent larval kill at 0 ft. or directly under the flight of the plane. Evidently some fenthion, either on the SiO_2, NH_4Cl particles, or alone, which could not be seen or was not noticed, descended directly down from the site of application. Figure 5 shows the first visible fog to reach the ground surface to be at least 50 feet from the beginning of the target area. The exact dosage applied could not be determined, since the rate of fall-out of the fenthion was not known. However, this test was based on a 0.05 lb./acre (Baytex) at a 450-foot swath width and since the swath width was doubled, theoretically the dosage was 0.025 lb./acre.

The grass runway had a slight rise in the center for water run-off and was paralleled on the right by a railroad and on the left by a gravel road and a ditch.

TABLE 1.—Swath width studies with fenthion applied by aerial cold-chemical fog over cartons of *Aedes aegypti* larvae.

Number of feet downwind[a]	Corrected percent mortality[b]
0	100.0
100	88.8
200	92.8
300	75.5
400	56.6
500	64.4
600	62.9
700	57.8
800	54.3
900	65.7

[a] Waxed, 32 oz. cartons contained 10 2nd and 3rd instar larvae each and were replicated 5 times, spaced 65 feet x 100 feet apart on a grass airplane runway.

[b] Abbott's formula used for correcting for natural mortality.

FIG. 5.—Grass runway and road where cartons of larvae were placed for swath width study. (1) Waxed carton farthest to left of treated area and at 0 feet, (2) car used to mark flight of plane.

The chemical-fog dispersed to both sides of the air strip and was especially attracted to depressions such as the ditch. Consequently, in the cartons near the ditch the chemical had a greater larval kill, beyond 500 feet. Up to 500 feet there was no difference in the kill percentage because the fog was more evenly distributed.

From this test the author concluded that a 200-foot swath would be adequate for future tests.

Test 2. Baygon (1½ lb./gal.) and fenthion (8 lb./gal.) was combined with $SiCl_4$ to determine its effectiveness against adults and larvae.

A series of 32-oz. waxed cheese cartons containing 10 *A. aegypti* larvae each were placed under different vegetative cover and replicated at least three times. Equal numbers of covered cartons were used as untreated checks. The effect upon natural mosquito larval populations within the test area was determined by making 20 larval dip counts immediately prior to the application, and at 24 and 48 hours after the application.

The effect of the treatment against adults was determined by placing three-CDC type light traps within the center of the treated areas two nights prior to, and one night after treating. The treated area consisted of mostly swamp with some adjacent farm land. The vegetative growth varied from cattails and low shrubbery to trees varying from 40 to 75 feet tall. Eighty oz. of fenthion, 125 oz. of Baygon, and 205 oz. of $SiCl_4$ were mixed and applied at the rate of 0.05 lb. of fenthion and 0.014 lb. of Baygon per acre. The application was made at 1015 hours from an altitude of 75 to 100 feet. With sunny to partly cloudy conditions, the wind ranged from 10 to 12 m.p.h., temperature was 80° F., and the relative humidity was approximately 65 percent.

RESULTS AND DISCUSSION. Table 2 shows the larval control under heavy canopy was only 44 percent, whereas 100

TABLE 2.—Results of Baygon: Fenthion (0.05:0.014 lb./acre) combination applied by chemical fog for mosquito larval control. Thirty-two waxed cartons containing 10 *Aedes aegypti*, 2nd and 3rd instar larvae, were placed under different types of foliage and compared with natural infestation of *A. sollicitans* larvae. Each type of foliage was replicated at least three times.

Sites	Average number of larvae killed/carton		Corrected % mortality	
	Treated	Untreated	24 hrs.[b]	48 hrs.
Heavy canopy[a]	5.5	2	44	..
Light canopy[c]	10.0	0	100	..
No canopy[d]	10.0	0	100	..
Natural infestation[e]	....	..	42	74

[a] Trees 30–40 feet high—good leaf coverage.
[b] Abbott's formula used for correcting natural mortality.
[c] Little coverage—such as in cattails or mature corn field.
[d] Open area.
[e] Based upon 20 larval dip counts prior to and after treatment.

percent control was obtained under light canopy and in areas with little to no vegetative cover. The chemical-fog was "attracted" to the vegetative cover, and, as the fog passed through an area it raised or lowered according to the height of the foliage. This layering of the fog in foliage 30–40 feet above the cartons may explain the poor kill obtained in this particular site.

The natural larval population yielded only a 42 percent kill at 24 hours and a 74 percent kill at 48 hours. The increased kill at 74 hours was not due to larvae pupating and emerging as adults as the larvae were in the second and early third instar stages at the time of application. It is possible, however, that a considerable amount of the insecticide was deposited on the cattails in the swamp and did not reach the water. No 48-hour count was made on the *A. aegypti* larvae as the author was not sure of remaining in the area another day. Therefore, all cartons containing *A. aegypti* larvae were dumped on dry land at the end of the 24-hour period to prevent any possible contamination of the area with this species of mosquito.

The data from the CDC light traps showed that a 75 percent reduction of adults was obtained in 24 hours. This was based upon an average of 148 adults captured per trap during the pre-treatment period. The adults were from three genera, i.e., *Aedes, Anopheles,* and *Culex.*

Because this test was made during midmorning and the traps were placed in the area at 2,000 hours, there was sufficient time for mosquitoes to migrate into the area from outside, and for some from untreated areas to enter the traps. If the application had been at dusk and the traps placed immediately after a treatment, the control might have appeared greater. These observations show the disadvantages of using small acreage for studies of this type.

Test 3. This test was designed to compare the effectiveness of an ULV application of fenthion compared with that of a cold-chemical fog application. Three waxed cartons each containing 10 *A. aegypti* larvae as described above were placed within the following locations: (1) open area; (2) grassy open area; (3) under shrubs, and (4) under trees. This arrangement was replicated five times within the treated area. Two of the cartons were covered and one uncovered during the ULV application of fenthion at the rate of 0.05 lb./acre. This application was accomplished by use of the plane's own ULV spray system as described by Knapp and Pass (1966), and was applied at 0700 hours. The temperature was 60° F., relative humidity was 100 percent, and the wind was at 2 m.p.h.

One hour after the ULV application, the uncovered carton was covered and another carton uncovered for the chemical-fog application. For this test 51.2 oz. of fenthion was mixed with 76.8 oz. of $SiCl_4$. A 400-foot swath was to be used in this test, however, owing to an error a 200-foot swath was used, thus theoretically 0.1 lb. of Baytex was applied per acre instead of the 0.05 lb./acre.

When the fog had settled, approximately 1 to 1½ hours later, the covers on all cartons were removed. Larval mortality counts were made 24 hours later.

RESULTS AND DISCUSSION. Table 3 shows the results of the two different application techniques. Although the cold-chemical fog showed a greater kill percentage in all cases, it was not so great as would be expected since the dosage was twice the application rate as the ULV. Again it is not known how much fenthion actually was applied to the entire area because the fall-out of the chemical fog is not known. The author feels that more data are needed before any conclusions can be reached as to what application method is the most effective for mosquito control.

TABLE 3.—The effectiveness of fenthion against *Aedes aegypti* larvae when applied as ULV and in a cold-chemical fog.

	Corrected average percent mortality[a]	
	ULV	Chemical fog
Sites[b]	(0.5 lb./acre)	(0.1 lb./acre)
Open	58.5	78.0
Grass	35.9	48.4
Shrubs	0.0	10.3
Trees	3.9	27.6

[a] Abbott's formula used for correcting for natural mortality.

[b] Two treated and one untreated cartons of 10 larvae each were placed in each location and replicated at 5 different areas.

Test 4. To determine the effects of Baygon on adult mosquitoes, *Aedes sollicitans* (Walker), without the addition of fenthion, Baygon (1½ lb./gal) was mixed with equal parts of $SiCl_4$. This was applied over a wooded and low shrub area at an altitude of 75 to 100 feet and at the rate of approximately 0.02 lb. (0.0325 oz.) per acre. This application was made at 0800 hours under cloudy conditions with the wind at 2 m.p.h., the temperature at 68° F, and the relative humidity at 100 percent.

Adult mosquito counts were made just prior to the treatment by two persons standing facing each other and counting the adult mosquitoes on or in the immediate vicinity of the other person for 30 seconds. Post-treatment counts were conducted at intervals of 15 minutes 1, 2, 6 and 12 hours after treatment.

RESULTS AND DISCUSSION. The conditions for applying the cold-chemical fog were ideal; the fog dispersed well and settled into the trees and stayed for 20–30 minutes. As the wind velocity and temperature increased the fog started to disperse. Table 4 shows the effectiveness of the treatment against the adult mosquitoes. Fifty percent reduction was achieved at 15 minutes and 76, 93, 90 and 93 percent at 1, 2, 6 and 12 hours, respectively. A check on the adult mosquito population 24 hours later showed an increase in the number of mosquitoes present. These were believed to be mosquitoes that drifted in from untreated adjacent areas as well as pupae emerging from the swamps. Therefore, no other post-treatment counts of adult mosquitoes were made.

TABLE 4.—The effectiveness of 0.325 ounce of Baygon per acre against adult mosquitoes when applied in a cold-chemical fog.

Hours after treatment	Adult counts/ 30 seconds	% Adult reduction
0.00	20.0	..
0.25	10.0	50
1.00	4.8	76
2.00	1.4	93
6.00	2.1	90
12.00	1.5	93

GENERAL DISCUSSION. The cold-chemical fog has the advantage that it may be used under more adverse weather conditions than ULV applications. It also "seeks out" low depression areas and follows the curvature of the land until the fog disperses. It penetrates foliage, has a tendency to rise upward to tree top level in wooded areas, and to descend to lower shrubbery when it leaves the higher foliage. The fog produced is dense, which may or may not be advantageous in controlling insects, although it is a disadvantage or a hazard in mosquito control work in populated areas. The author believes that the density of this fog may be decreased without effecting its efficacy. The swath width can vary depending upon the wind velocity, relative humidity, and temperature. The greater the air movement, the less chance of an adequate deposit of insecticide in the target area, and, the greater the temperature and lower relative humidity, the narrower the swath width.

A disadvantage of the cold-chemical fog over ULV is the increased volume of solution to be carried by the aircraft. However, for ground application this may not be a problem and would probably be more economical than the conventional thermal fog method.

CONCLUSION. Although the chemical fog looks impressive as one watches it disperse, data to date show that aerial application of Baygon or fenthion by this method is not superior to ULV application for mosquito control. Further work is needed on this method of dispensing insecticides, especially on the methodology involved, its hazards, if any, the effectiveness against other insect pests, and its compatibility with different insecticides.

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