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STUDIES ON FINE SPRAY AND AEROSOL MACHINES FOR CONTROL OF ADULT MOSQUITOES[1]

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During 1951 and 1952 a comparative study was made of 5 machines for their ability to control infestations of adult *Aedes* mosquitoes about camps in Canadian woodland. They comprised the Microsol generator (Wilson *et al.,* 1949), the Husman sprayer,[4] a recent modification of the Besler generator (Brescia, 1946; Wilson *et al.,* 1949), the TIFA machine (Dickinson *et al.,* 1948; Horsfall, 1950; Peterson, 1952), and the Dyna-Fog generator (McDuffie *et al.,* 1950; Yeomans, 1950).

Determinations were made of the droplet spectra produced with oil solutions of DDT emitted at various rates; the droplet spectra at various distances downwind; the portions of the clouds that were deposited on the ground; the amount of DDT that reached various distances downwind both in the open and in the woods; and the percentage reduction in landing rates of *Aedes* mosquitoes obtained in woodland for distances up to 400 yd. downwind.

MATERIALS: The following 5 machines were tested: 1. The Microsol Mechanical Aerosol Generator, Agricultural Unit Model 403, Silver Creek Precision Corporation, Silver Creek, N. Y. (Fig. 1). The insecticide is mechanically atomized by being thrown off the periphery of a sheaf of twenty-one 8.5-in. discs rotating at 8125 to 9750 r.p.m. Power is supplied by a 7½-h.p. Wisconsin engine, with a gasoline consumption of 0.6 g.p.h. at 3000 r.p.m. The weight of the complete unit is 442 lb. empty.

2. The Husman Pneumatic Fine-atomizing Sprayer, made by C. N. Husman, U. S. Bureau of Entomology, Orlando, Fla. (Fig. 2). The insecticide is atom-

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[4] See article by C. N. Husman, page 134, this issue of *Mosquito News.*—Ed. Note.

ized by air pressure at 8 to 15 p.s.i. supplied to a group of six 0.34-in. air-mix nozzles (No. 120-6-35-60 air combined with No. 4010 liquid in assembly No. 30, Spraying Systems, Chicago) by a rotary-vane compressor supplying 8.3 c.f.m. Power is supplied by a 1¼-h.p. Briggs and Stratton engine, with a gasoline consumption of 0.24 g.p.h. The weight of the complete unit is 125 lb. empty.

3. The Bes-Kil Aerosol Generator, Model A-120, Besler Corporation, Emeryville 8, California. The insecticide is atomized by steam at a temperature of 500 to 700° F. and a pressure of 100 to 150 p.s.i. The steam and the insecticide (pumped at 30 to 45 p.s.i. and not heated) meet at a single nozzle. Heat and power are supplied by a 1½-h.p. Lauson RSC-677 engine, with a gas consumption of 0.15 g.p.h. at 2800 r.p.m. The water for the steam is pumped at either 40 or 80 g.p.h., and the fuel oil for the burner to heat the steam is expended at 0.65 g.p.h. The weight of the complete unit is 920 lb. empty.

4. The TIFA, Todd Insecticidal Fog Applicator, Series 40-E, Todd Shipyards Corporation, New York, N. Y. (Fig. 3). The insecticide is injected into a fog-head through which hot air is blown at 1000° F., and 150 c.f.m. The air-blower, fuel pump, and insecticide pump are all operated at 1300 r.p.m. by a 6½-h.p. Briggs and Stratton engine turning at 2460 r.p.m. and consuming gasoline at 1.8 g.p.h. The insecticide is pumped at a pressure of 25 to 30 p.s.i. The fuel for the burner is pumped, from a gasoline tank shared with the engine, at 13 g.p.h. and 50 to 70 p.s.i. The weight of the complete unit is 600 lb. empty.

5. The Dyna-Fog Jet Insecticidal Fog Generator, Dyna-Fog Corporation, Dayton Municipal Airport, Vandalia, Ohio (Fig. 4). The insecticide is injected into the exhaust of a pulse-jet engine producing 60 explosions per second and combusting gasoline at 2.5 g.p.h. It is dispensed from a separate 17-gallon tank by utilizing an air-push of 6 p.s.i. borrowed from the engine. The weight of the unit, exclusive of the insecticide tank, is 95 lb. empty.

Three DDT formulations were employed in the tests. The first was a 5 per cent solution in fuel oil (Shell Oil Co.) supplied to the Canadian Army in 1951 on special order; the solvent was reported as kerosene in the 1952 issue, but presumably little difference is involved. This formulation is standard for treating army camps in Canada with the TIFA machine; its viscosity is 38.7 SSU (Table 1). The third formulation tested was a 30 per cent concentrate of DDT in a methylated aromatic solvent (probably unrefined polyalkylnaphthalenes) with a viscosity of 44.6 SSU. The second formulation was a 5 per cent solution made by diluting 1 part of the concentrate with 5 parts of Sovacide F (Socony-Vacuum Oil Co.). This was used because its low flash-point was suitable for the high temperatures generated by the Dyna-Fog and TIFA machines. All liquid volumes are quoted in this paper as imperial gallons (1 imp. gal.=1.2 U. S. gal.).

METHODS: The Microsol generator was mounted on the back of a 15-cwt. Dodge military truck, with the muzzle pointing backwards and upwards at an angle of 20° with the horizontal. The Husman sprayer was operated with the nozzle assembly held at breast height and directed downwind. The Bes-Kil generator was towed by a jeep; its single nozzle is 4 ft. above the ground, and it was directed downwind. The TIFA machine was mounted in the back of a 15-cwt. truck, with the fog-head held horizontal and pointed downwind. The Dyna-Fog generator was mounted on boards placed across the back of a jeep; when stationary it was supported on a platform 24 inches above the ground.

The droplet sizes of the sprays and aerosols were assessed by drawing air samples through cascade impactors (Casella) at 17.5 liters per minute (Fig. 5). Evacuated drums of 25 gal. capacity, with a valve set at the appropriate intake rate, were used for this purpose; a glass tap was also inserted to allow snap samples to be taken close to the generator. The droplets were impacted on microscope slides coated with a thin film of a liquid silicone compound (G. E. Drifilm 9987). The coating was applied with cheesecloth, and it was thinned down by polishing it with at least 20 brisk strokes of a cheesecloth pad. Upon impact on this coating, the droplets produced lenses the diameters of which were approximately twice those of the droplets; the droplet/lens ratio, or spread factor, was determined by the focal length method (May, 1945) to be approximately 0.5 (Table 1), and

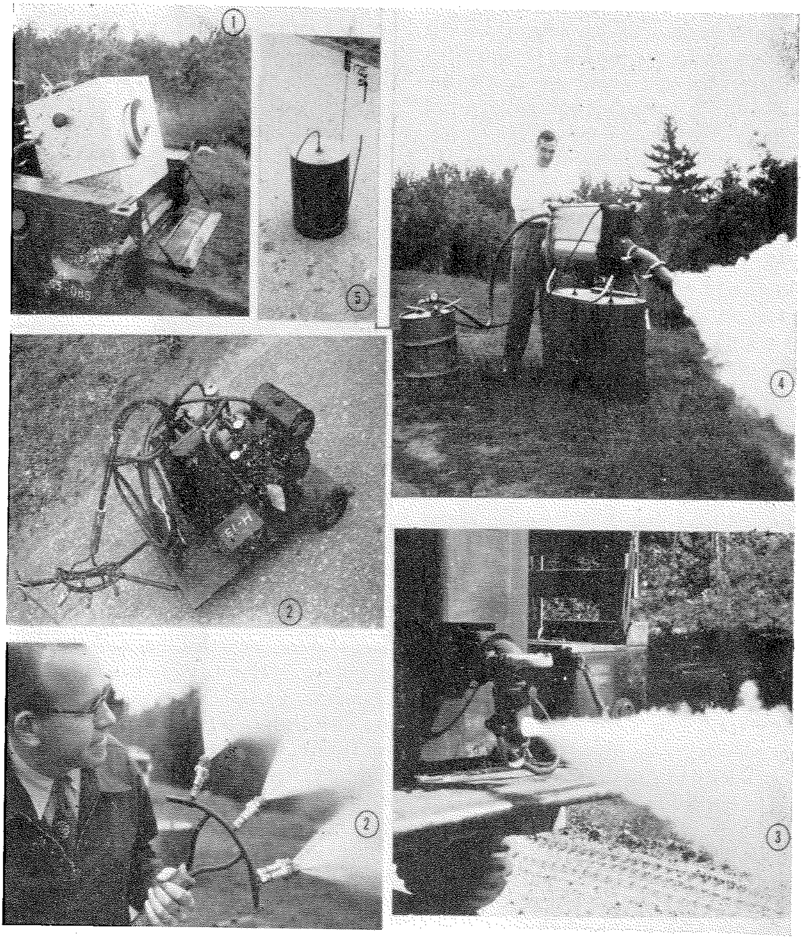

FIG. 1.—Microsol mechanical aerosol generator mounted in 15-cwt. truck, and elevated at 20° to the horizontal.

FIG. 2.—Husman pneumatic fine-atomizing sprayer. A (upper). Gasoline engine, compressor, and 5-gal. tank. B (lower). The air-mix nozzles, with air and liquid leads.

FIG. 3.—Todd insecticidal fog applicator (TIFA); note the clean break-away from the fog-head.

FIG. 4.—Dyna-Fog jet insecticidal fog generator; the unit with separate insecticide tank.

FIG. 5.—Cascade impactor, with glass tap and evacuated drum.

TABLE 1.—Physical constants of formulations employed

	Specific Gravity	Viscosity SSU at 70° F.	Refractive Index	Spread Factor
5% DDT in fuel oil (Shell)	0.845	38.7	1.46	0.52
5% DDT in Sovacide F	0.856	41.2	—	—
30% DDT in methylated aromatic	1.075	44.6	1.56	0.48

this factor was applied to assessments with all three oil formulations employed. The droplets were measured by means of a Patterson-Cawood ocular micrometer inserted into a compound microscope fitted with a mechanical stage. They were tallied according to size categories, and hence the total volume represented by the droplets in each size category could be computed. From these figures, the median diameter by mass (m.m.d.) was determined by the graphical method (Yeoman, 1949), with the modification that the upper limits of the categories, and not the mid-diameters, were used as ordinates.

Two other sampling methods were employed to confirm the cascade impactor results. Silicone-coated microscope slides were drawn by hand smartly downwards through the aerosol cloud. Slides coated with a glycerol-gelatin mixture (Hurtig and Perry, 1950) were exposed to catch the droplets in their spherical state, but attempts to use them in the cascade impactor were not successful, since the coatings either were too messy or became too hard. Initial samples of the cloud were taken 6 ft. from the generator, the distance being increased to 15 ft. with the Bes-Kil. The sampling height for the impactors was 4 ft.

The volume of material that fell out of the cloud on to the ground was measured by two methods. For short distances, lengths of a roll of paper towelling 10 in. wide were spread to form a continuous area; they were weighed before and after the machine emitted over it for a period of 1.5 seconds duration. For the longer distances, the fall-out was sampled by exposing 4-inch petri-dishes coated with silicone; the droplets deposited were measured and from them the total volumes were computed.

When the performance of the machines was sampled at distances exceeding 50 yards, they were towed along an emission line of 100 or 200 yd. at right angles to the wind direction, and the sampling points were located along a line running downwind of the mid-point of the emission line. This procedure was employed for the biological experiments in woodland as well as for the physical assessments. The speeds at which the machines were towed were between 1.2 and 3.4 m.p.h., being so adjusted that (with 5 per cent DDT solution) approximately 0.7 gal. containing 0.35 lb. of DDT were emitted for every 100 yd. of frontage. The times allotted each machine for covering 100 yd. were: Microsol, 2¼ min.; Husman, 2¾ min.; Bes-Kil, 1 min.; TIFA 2¼ min.; Dyna-Fog, 1½ min. When 30 per cent concentrate was emitted, the speeds were increased approximately 3 times.

The wind speeds at the time of application were measured by a thermopile Air-Meter (Hastings Instrument Co., Hampton, Va.). The temperature gradient, indicating whether there was upward convection (lapse) or air inversion, was measured by shielded thermocouples set up at heights of 1 m. and 2 m. and linked by a sensitive galvanometer.

The amounts of DDT reaching various distances downwind were sampled by means of 25-mesh copper screening cut into 9-in. squares, and held in a frame of ¾-in. angle iron at a height of 4 ft. and facing the oncoming cloud. For this method we are indebted to Dr. A. B. Hadaway, Colonial Insecticide Committee, who employed it in tsetse-fly control experiments in East Africa. The deposits were washed off the screens by immersing them in 120 cc. of acetone in a medical instrument dish, and the DDT was determined by the Schechter-Haller method (Schechter *et al.*, 1945) with the nitration period limited to 30 minutes. When an attempt was made to assess the filtering efficiency of the screens, by taking 3 of them together one behind the other, it was found that the deposit was evenly divided between them, and the total figure was equivalent to that obtained by exposing one alone.

Cascade impactors were not employed to obtain recoveries of DDT because the amount sampled was far too low to be detected even by the Schechter-Haller method. The total amount recovered in one impactor from the cloud produced by the TIFA at a distance of 50 or 100 yd. was determined, by adding up the volumes of all the droplets, to be between 1 and 10 million cubic microns, which would not contain more than 0.05 to 0.5 micrograms of DDT. However, when an experiment was performed in which 30 per cent concentrate was emitted in 2 passes of the machine and eight impactor samples were added together, the amount recovered was increased by a factor of 96, and the DDT thus obtained at 100 yd. was determined to be 98 micrograms. Similarly, 48 micrograms were recovered at 200 yd. and 58 micrograms at 400 yd. If these figures are recalculated to the basis of 0.35 lb. of DDT emitted per 100-yd. frontage, they become 9.0, 4.4, and 5.3 micrograms respectively for the sampling rate of 140 l. per min. (8 by 17.5). If these figures are compared with those shown in table 9 which were obtained with the screens that might be expected to sample at approximately 10,000 l. per min. (*i.e.*, in a 7-m.p.h. wind, 346 cu. ft. passed through the screens in 1 min.), it will be seen that the screens are only about one-sixth as efficient as the cascade impactors in recovering aerosol material.

The effect of the DDT sprays and aerosols in reducing the landing rates of adult *Aedes* mosquitoes was assessed in open second-growth jack pine stands and in dense mixed woods containing spruce and poplar, at Petawawa, Ontario. The species represented in the population were as follows, in order of their abundance: *Aedes sticticus* (Meig.), *A. canadensis* (Theo.), *A. stimulans* (Wlk.), *A. excrucians* (Wlk.), *A. fitchii* (F. & Y.), *A. intrudens* (Dyar), *A. trichurus* (Dyar), *A. punctor* (Kby.) and *Mansonia perturbans* (Wlk.). The population was assessed by a team of 4 or 5 men shortly before the application and within 1 hr. after it; they went into the area on a compass bearing and paced out the intervals of 100 yd. for the 4 sampling points. The landing rate was determined, after waiting at the point for 1 min., by the number of landings of mosquitoes on the front of the trousers between knees and waist.

RESULTS: The delivery rates and droplet sizes produced by these machines at their normal settings are shown in tables 2 to 6. The values shown for the droplet sizes in many cases represent the averages of several determinations. For each machine the droplet sizes, as represented by the mass median diameters, rise as the delivery rate increases. The droplet sizes are also larger, and the atomization less, as the viscosity increases; although the consequent decrease in emission rate may minimize this difference. The best basis for comparing machines is to consider their performance at the same emission rate throughout; approximately 20 gal. per hr. is the most usual and convenient figure.

With the Microsol generator (Table 2) fine sprays are produced whose droplets are considerably larger than aerosol size, and constitute a compact spectrum from which the smaller size-classes are entirely lacking (Fig. 6). Smaller droplet sizes are obtained at lower emission rates, but even when it is reduced to 4 g.p.h. the atomization fails to depart from that of a fine spray. The settings for emission rate on this machine are approximate, depending on the degree of opening of a

TABLE 2.—Microsol generator: delivery rates (imperial gallons per hour) and droplet sizes (median diameter by mass, in microns); 5 per cent DDT in fuel oil (Shell)

Adjustment Setting	Delivery Rate g.p.h.	Mass Median Diameter microns
3000 r.p.m., 1/16 open	4	71
3000 r.p.m., 1/8 open	19	90
2500 r.p.m., 1/8 open	18	134
2500 r.p.m., 1/4 open	40	258

½-in. cock valve with a semicircular dial crudely engraved.

With the Husman sprayer (Table 3), the output is within the fine spray class, with a small component (approximately 10 per cent of the volume) falling within the aerosol class below 20 microns diameter. The emission rate increases more steeply than the air pressure applied, but the droplet sizes do not show a very significant increase. This is presumably because the rise in emission of insecticide solution is almost compensated by a rise in the pressure of air supplied to atomize it. The droplet spectrum with this sprayer approximates a normal frequency curve, extending down to the finest sizes, but it is sufficiently asymmetrical to include droplets of rather larger size than normal (Fig. 6).

The Bes-Kil generator (Table 4) can emit material at rates that are more than double those of the other machines. Although it is an aerosol generator, much of the large volume emitted falls into quite large size-classes, and thus the mass median diameter values are high (Fig. 6). The spectrum does not follow a normal frequency curve, but is more in the form of a plateau with occasional peaks, so that as much as 40 per cent of the volume may fall in the aerosol size-class. Nevertheless, at least 60 per cent of the output of this machine is lost as far as aerosol application is concerned.

The emission rates obtained with the TIFA machine are shown in Table 5, along with the mass median diameters determined at setting 10. Further determinations were not made, since a more complete set of droplet size data has already been published (Peterson, 1952). The droplet spectrum with this machine approaches a normal frequency curve (Fig. 6), so that a mass median diameter of 17 microns involves only 30 per cent loss in droplets larger than 20 microns, and only 1 per cent in the screening smoke class below 3 microns. The spectrum given by 5 per cent DDT solution emitted at 19 g.p.h. by the TIFA machine represents a satisfactory aerosol cloud.

The data obtained from the Dyna-Fog generator are tabulated in Table 6. Here a large number of droplet size determinations were made, with cascade impactors as well as hand-drawn slides; but the variation between samples was so great that it is impossible to quote single average values for the mass median diameter. One characteristic of the spectrum (Fig. 6) is that a very large proportion of the volume falls in the very small size-classes; these screening-smoke droplets give the aerosol from the Dyna-Fog its spectacular appearance. There is also a component of larger droplets extending into quite high size-classes. These characteristics are also evident in figures previously quoted for this machine (Yeomans, 1950). When sampled at a distance of 2 yd., and particularly with 5 per cent DDT in fuel oil emitted at setting 4, the fine droplets of the aerosol are still in process of recondensing; the contents of the cascade impactor reek when it is opened, and a considerable volume of droplets of various sizes and shapes are deposited on the fourth (last) slide of that apparatus. On the other hand, when this cloud is sampled by means of hand-drawn slides, an unusually large proportion of the bigger droplets are picked up, and remarkably high mass median diameters are obtained. Only with 30 per cent concentrate emitted at setting 8 could apparently normal droplet spectra be obtained.

The droplet sizes from the different machines that reach various distances downwind over open terrain are tabulated in Table 7. With the Microsol generator, the finest droplets in the spectrum reached

TABLE 3.—Husman sprayer: delivery rates and droplet sizes

	5% DDT in Fuel Oil (Shell)		5% DDT in Sovacide F		30% DDT in Methylated Aromatic	
	g.p.h.	microns	g.p.h.	microns	g.p.h.	microns
8 p.s.i.	7	33	—	24	7	30
10 p.s.i.	12	42	—	68	11	65
12 p.s.i.	15	36	11	36	14	35
15 p.s.i.	21	40	17	98	18	70

TABLE 4.—Bes-Kil generator: delivery rates and droplet sizes

	5% DDT in Fuel Oil (Shell)		5% DDT in Sovacide F		30% DDT in Methylated Aromatic	
	g.p.h.	microns	g.p.h.	microns	g.p.h.	microns
500° F., setting 4	40	54	—	—	40	52
700° F., setting 4	40	26	—	26	40	52
500° F., setting 8	68	45	—	—	65	98
700° F., setting 8	68	102	—	90	68	82

TABLE 5.—TIFA: delivery rates and droplet sizes (for further data see Peterson, 1952)

	5% DDT in Fuel Oil (Shell)		30% DDT in Methylated Aromatic	
	g.p.h.	microns	g.p.h.	microns
Selector setting 10.2	19	17	17	26
Selector setting 11.5	24	—	20	—
Selector setting 15.6	39	—	31	—

TABLE 6.—Dyna-Fog generator: delivery rates and approximate droplet sizes.

	5% DDT in Fuel Oil (Shell) g.p.h.	5% DDT in Sovacide F g.p.h.	30% DDT in Methylated Aromatic g.p.h.	Range of m.m.d.'s for All 3 Formulations microns
Setting 4	18	13	13	1–5
Setting 6	28	21	20	3–30
Setting 8	32	32	27	10–50

as far as 100 yd. but no farther. These droplets are, of course, considerably larger than aerosol size, and they drifted for that distance because they were thrown out at an angle of 20° with the horizontal, by turbine-type vanes located behind the discs, to a maximum height of 8 ft.

With the Husman sprayer, a residuum of fine droplets succeeded in reaching distances up to 400 yd. From 200 to 400 yd. distant from the source, only the finest droplets are present in the cloud, regardless of the machine employed. At 100 yd., the recoveries from the Husman and Bes-Kil machines were of larger droplet size than that from a true aerosol generator such as the Dyna-Fog. But at 200 to 400 yd., the only droplets of the Bes-Kil's output to reach that distance were very small, which may have a bearing on the slight effect on mosquitoes.

The amounts of material emitted that

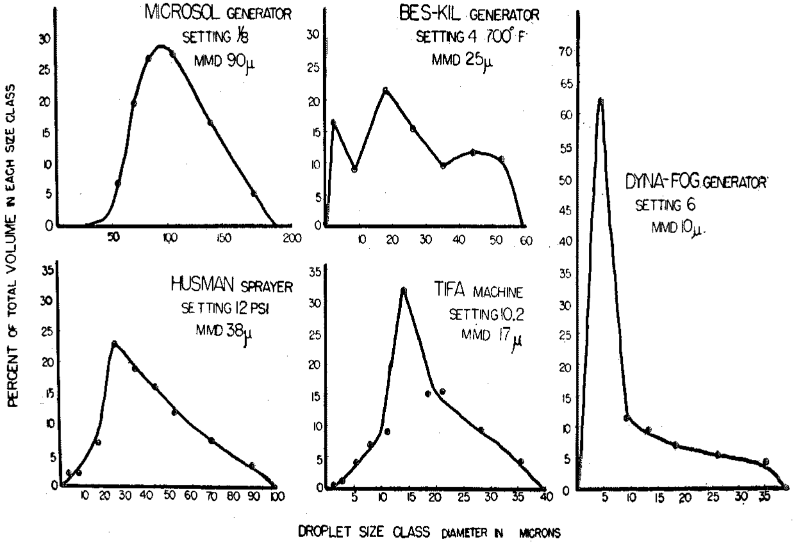

Fig. 6.—Droplet spectra obtained by the 5 machines with 5 per cent DDT in fuel oil.

fell out of the air-borne cloud and were deposited on the ground are shown in Table 8. The Microsol generator deposited all its material within a distance of 150 yards downwind, and only 30 per cent of the volume drifted farther than 50 yards. With the Husman sprayer, the bulk of the material remained air-borne for considerable distances. However, in a light wind a considerable proportion (at least 7 per cent) fell to the ground within 5 yd. of the nozzles. The ground recoveries determined for this and the following machines tested were considerably lower than the true figures; for example, the proportion of the output of the Husman sprayer at 12 p.s.i. that reached 300 yd. was certainly not as much as 90.6 per cent, as the figures in Table 8 appear to indicate.

With the Bes-Kil generator there was a significantly high ground contamina-

TABLE 7.—Mass median diameters, in microns, of airborne droplets at various distances; 5% DDT in fuel oil

Generator	Wind Speed m.p.h.	Distances Downwind from Source, in Yards					
		25	50	100	200	300	400
Microsol							
3000 r.p.m., 1/8 open	7	42	34	36	—	—	—
Husman							
10 p.s.i.	11	—	—	15.5	3.5	—	5.5
12 p.s.i.	1	—	—	6.2	4.4	—	—
Bes-Kil							
500° F., setting 4	9	—	—	5.0	2.7	1.9	1.3
700° F., setting 4	9	—	—	25	2.0	2.3	1.8
Dyna-Fog							
Setting 6	3	—	9.2	5.8	3.7	—	2.5

TABLE 8.—Percentages of total volume emitted that fell to the ground within the various distances downwind from the source; 5 per cent DDT in fuel oil

Generator	Wind Speed m.p.h.	Distances Downwind from Source, in Yards							
		5	10	25	50	100	150	200	300
Microsol									
3000 r.p.m., ⅛ open	4	6.4	18.3	42.1	70.8	97.2	100	100	100
Husman									
12 p.s.i.	1	6.98	7.17	7.18	7.19	Not determined			
10 p.s.i.	11	0.25	3.5	7.1	8.0	8.7	9.0	9.2	9.4
Bes-Kil									
500° F., setting 4	6	0.8	1.7	3.8	3.81	3.82	3.821	3.822	3.8227
700° F., setting 4	9	0.5	2.3	4.06	4.13	4.16	4.18	4.19	4.192
TIFA									
Setting 10.2	4	0.002	0.004		No further appreciable fall-out				
Dyna-Fog									
Setting 6	4	0.01			No further appreciable fall-out				
Setting 5	4	0.02			No further appreciable fall-out				

tion, which reached its maximum between 10 and 15 yd. away from the nozzle. On the other hand, the loss of air-borne material from the TIFA machine was very small. But it was sufficient to make the grass immediately in front of the fog-head reek immediately after the cloud had passed over it.

With the Dyna-Fog generator, there was a greater deposit immediately in front of the machine than with the TIFA, owing to the presence of a few larger droplets in the cloud. Although still negligible when 5 per cent DDT in fuel oil was used, the amount deposited in the first 5 yd. was between 0.25 and 0.6 per cent when the 5 per cent solution in Sovacide or the 30 per cent concentrate was emitted at setting 8. Evidently the insecticide solution is impacted on the inner walls of the emission pipe, runs down to the flange at the end, and is atomized there as coarse droplets. With the TIFA, on the other hand, an encircling blast of air in the fog-head carries the material clear out of the atomizing cup (Fig. 3).

The recoveries of DDT from the air-borne cloud are shown in Table 9 for passage over open terrain, and in Table 10 for passage through woodland. The woods had filtered out most of the output from the Husman sprayer by the time it

TABLE 9.—Recoveries of DDT, in micrograms, on 81-sq.-in. screens held at various distances downwind of emission over open terrain; 5 per cent DDT in fuel oil

Generator	Wind Speed m.p.h.	Distances Downwind from Source, in Yards*					
		25	50	100	200	300	400
Microsol	2–5	310	405	102	0	0	0
Husman	8	—	1165	85	41	41	48
Bes-Kil	8	—	339	178	152	144	140
TIFA	5–9	—	468	213	99	93	59
Dyna-Fog	5–9	—	113	72	54	44	50

* Results calculated on the basis of 0.35 lb. of DDT emitted per 100-yd. frontage. Average of 2 runs for Microsol, and of 3 runs each for TIFA and Dyna-Fog.

TABLE 10.—Recoveries of DDT, in micrograms, on 81-sq.-in. screens held at various distances downwind of emission through woodland; 5 per cent DDT in fuel oil

	Distances Downwind from Source, in Yards*					
Generator	25	50	100	200	300	400
Microsol	37	51	85	0	0	0
Husman	—	357	55	10	0	0
Bes-Kil	—	—	33	21	2	0
TIFA	—	—	72	82	59	43
Dyna-Fog	—	—	48	39	20	15

* Results calculated on the basis of 0.35 lb. of DDT emitted per 100-yd. frontage. Average of 2 runs for Microsol, TIFA, and Dyna-Fog.

had reached a distance of 300 yd. Broad-leaved trees close to this sprayer intercepted so much material that the foliage glistened with it. The cloud from the Bes-Kil did not carry much DDT beyond 200 yd. into woodland (Table 10). On the other hand, with the TIFA and Dyna-Fog significant amounts of DDT were still air-borne after the cloud had travelled as much as 400 yd. through woods. Table 9 shows that the decrease in air-borne material was least abrupt in the case of the Dyna-Fog, which gives the finest droplet spectrum.

Applications could be made to woods from roads running through them provided there was a sufficient wind speed to move the cloud off the road; the machines were driven as close to the boundary of the trees as possible. Under conditions of strong upward convection, it was impossible for the cloud to enter woodland unless the wind speed in the open exceeded 10 to 15 m.p.h., but in the evening as the temperature gradient approached zero it was possible to treat woodland when the free wind speed was only 4 m.p.h. Where the road had a cleared border on the upwind edge the task became easier, but when it was enclosed between woods the wind speed on the road might be less than one-tenth of that in the open. It was possible on many occasions to treat woodland satisfactorily in the middle of the day.

The reductions in landing rates effected by these machines emitting into woodland are shown in Table 11. These reductions do not necessarily imply that the mosquitoes were killed. The amounts of DDT applied in these tests approximated 0.35 lb. per 100 yd. of frontage, equivalent to a dosage of 0.04 lb. per acre if the distance between application is 440 yd. This level of application effected a partial reduction in landing rate and thus furnished a convenient basis of comparison for the performances of the several machines; for operational use in Canadian woodland this dosage could be considerably increased, for example, to 0.10 lb. per acre. There was no significant difference in biological effect whether a given amount of DDT was applied in 5 per cent solution or in the 30 per cent concentrate (see last line, Table 11).

The Microsol generator was tested on two occasions, when the wind speed was 6 m.p.h. and strong upward convection prevailed, circumstances that should increase the distance travelled by the spray. However, no reduction in the mosquito landing rate could be detected beyond 250 yd. downwind.

With the Husman sprayer, good results were obtained under conditions of considerable lapse, the effect extending for 400 yd. through open pine woods. But when the spray was emitted through dense mixed woods, the biological effect was mediocre at 100 yd. and insignificant beyond that. In the two tests performed with the Bes-Kil generator, only slight reduction of mosquitoes was obtained at the greater distances in dense mixed woods.

TABLE 11.—Biological effectiveness of 5 machines against *Aedes* mosquitoes in eastern Canadian woodland

Machine employed	lb. DDT emitted per 100 yd.	Percentage Reduction in Landing Rate 100x	200x	300x	400x	Average	Conditions
5% DDT in Fuel Oil (Shell)							
Microsol*	0.28	77	71	0	0	37	Strong lapse, strong wind
Husman	0.27	48	33	24	0	26	Dense
Bes-Kil	0.35	73	41	32	10	39	mixed woods
Husman	0.38	94	93	71	61	80	Considerable lapse,
Dyna-Fog	0.44	98	62	54	48	66	open pine woods
Bes-Kil	0.33	87	21	0	0	27	Dense
Dyna-Fog	0.45	97	92	87	69	89	mixed woods
TIFA	0.36	89	69	77	68	74	Open
Dyna-Fog	0.29	97	82	83	87	88	poplar woods
TIFA	0.38	97	96	90	75	88	Open
Dyna-Fog	0.35	95	90	89	72	87	poplar woods
30% DDT in Methylated Aromatic Oil							
Husman	0.70	61	14	27	32	34	Dense
Dyna-Fog	0.61	100	97	82	81	90	mixed woods
TIFA	0.35	74	98	82	28	72	Dense
Dyna-Fog	0.42	100	80	90	96	91	pine woods
TIFA	0.36	88	98	61	62	74	Dense
Dyna-Fog	0.42	94	90	78	67	83	poplar woods
Comparison of 5% DDT with 30% DDT							
TIFA, 5%	0.35	100	100	91	100	96	Open
TIFA, 30%	0.28	100	94	85	70	90	pine woods

* Percentage reductions at 25, 50, 75, 125, 150 and 250 yd. were 100, 85, 79, 78, 82 and 58 respectively.

The TIFA and the Dyna-Fog generator gave very much better results than the other three machines, especially at the greater distances. Nevertheless, the reductions in landing-rate were significantly lower at 300 and 400 yd. than in the first 200 yd. downwind of the generator (Table 11). There is a tendency for the Dyna-Fog to obtain higher reductions in landing rate than the TIFA, particularly when the woods are dense; the finer atomization with the jet generator presumably confers an advantage here. However, under conditions of high lapse rate over open woods, the situation is reversed.

DISCUSSION: It is clear from the results that the only two machines suitable for treatment of *Aedes* adults with aerosols in woodland are the TIFA and the Dyna-Fog. In these experiments, the Dyna-Fog gave slightly better results than the TIFA. In tests performed in Alaska (McDuffie *et al.*, 1950) the TIFA proved slightly more effective than the Dyna-Fog, when the terrain was more open with scattered spruce.

The TIFA, although a heavy machine, has a number of excellent features. It produces aerosols of comparatively uniform droplet size, the spectrum approximating a narrow probability curve. The droplet size may be modified by adjusting the emission rate while keeping the air-blast temperature constant, or by adjusting the temperature while keeping the emission constant (Peterson, 1952). The gasoline engine is reliable and runs smoothly, so that the machine may drain one 45-gal. drum of insecticide after another, and be safely left unattended for long periods. The TIFA machine may be conveniently bolted on a 15-cwt. truck.

The Dyna-Fog generator is light in weight and approximates the TIFA in biological effectiveness, despite an uneven droplet spectrum. The 17-gal. drum with which it is provided allows 45 min. of continuous emission before the machine is shut down for refill. The rate of gasoline consumption is higher than with the TIFA, and the presence of water in the gasoline is more liable to cause stoppage. When the jet stops, the insecticide solution in oil must be quickly turned off, because it ignites at the end of the muzzle. The noise level of the Dyna-Fog generator is high and sharp. Being a portable generator, it is not provided with hold-fast attachments for mounting in a vehicle. The Dyna-Fog is a precision machine that is simple in principle, but it requires skill and coolness in the operator.

The Bes-Kil gave comparatively low results against mosquitoes in woodland in spite of its higher emission rate. It appears that a large fraction of the fog is removed as impingement of larger droplets on foliage (in fact, this machine is used for just that purpose in orchard spraying). Much of the volume that remains air-borne is in extremely fine droplets too small to be very effective against mosquitoes. The heavier weight of this machine, coupled with its large appetite for water, also renders it unsuitable. However, it should be valuable for treating large expanses of open marsh with a few good roads traversing them.

The Husman sprayer shows remarkable versatility for a machine that is so light and simple in construction. Its rate of output is comparable to those of much heavier machines, and because of this large volume there is a sufficient amount of the smaller droplets available to affect mosquitoes at a distance. In open country and under conditions of high air turbulence this little machine can be very effective. If the present nozzles are replaced with designs that prevent the formation of the larger droplets in the spectrum, the Husman sprayer may be expected to provide a simple and effective means of controlling mosquitoes in any situation.

The Microsol generator is not adapted for control of adult mosquitoes on an area basis. However, it has possibilities for larval control; in these tests it produced 75 per cent mortality of *Aedes* larvae in a sheltered woodland pool 350 ft. away from the machine. Although similar results could be obtained with other mist-blowers (Turbine sprayer, Lawrence sprayer), the comparative lightness and compactness of the Microsol generator are an advantage.

In experiments performed with the TIFA in Alaska, 20 and 10 per cent DDT solutions were dispersed in open spruce forest at 5 U. S. gal. per mile of front (McDuffie *et al.*, 1950), the expenditures thus being respectively 0.47 and 0.23 lb. DDT per 100 yd. At 0.47 lb. per 100 yd., the reduction in landing rate in the first 200 yd. downwind was 99 per cent 3 hr. after application, and 98 per cent 12 hr. after application. At 0.23 lb. per 100 yd., the reduction 12 hr. after application was 80 per cent for the first 200 yd. downwind, and 33 per cent for the next 100 yd. In experiments in the Yukon Territory against *Aedes punctor* and associated species (Peterson, 1952) application of 5 per cent DDT solutions at 0.24 lb. per 100 yd. (8.05 lb. per 10,000 ft. quoted) in open pine forest gave complete reduction for distances of 100 to 800 yd. With the same expenditures in southern Ontario against *A. intrudens* and associated species in a forest of pine, willow, and poplar, complete reduction was obtained only in the first 50 to 100 yd. Experiments in Illinois with 5 per cent DDT solution (Horsfall, 1950) established that expenditures equivalent to 0.7 lb. per 100 yd. gave 80 per cent mortality of *Culex pipiens* exposed in cages 50 yd. downwind. Experiments in California (Dickinson, Merrit and Hough, 1948) gave complete control of *A. nigromaculis* for 440 yd. downwind at an expenditure of 0.47 lb. per 100 yd. (20 U. S. gal. of 5 per cent DDT per mile of front); their entire program against adults involved an average expenditure of 0.048 lb. of DDT per acre treated. The TIFA manufacturer recommends applying 5 per cent solution from a vehicle moving at 2 m.p.h., which, with the machine at setting 10, gives an expenditure of 0.25 lb. per 100 yd. (Todd, 1951); if parallel runs are made every 250 yd., the dosage is 0.05 lb. per acre, equivalent to the figure of 1 U. S. pint of 5 per cent DDT solution per acre quoted. Operations in Illinois, presumably following this method, obtained 97 per cent mortality at 100 yd., 95 at 200 yd., 92 at 300 yd., and 72 at 400 yd. (Todd, 1951). In the experiments described in this paper with *Aedes sticticus* and associated species in Ontario, the average figures for reductions in landing rate for an average expenditure of 0.36 lb. per 100 yd. over woodland are: 89 per cent for 200 yd., 77 per cent for 300 yd., and 58 per cent for 400 yd. from the machine.

The Besler aerosol generator, as the No. 1 inventor's modification model of Hochberg and LaMer, has been assessed for control of adults of *Aedes sollicitans, A. taeniorhynchus* and *Anopheles quadrimaculatus* in Florida (Brescia, 1946). When 5 per cent DDT emulsion was emitted at 1.9 lb. per 100 yd. (15 U. S. gal. per 1000 ft.), effective control was obtained for 1800 yd. in the open and 300 yd. in forest. When a further modified Besler (CWS Disperser E-15) was tested in Alaska with a 5 per cent solution at an expenditure of 1.5 lb. per 100 yd. (Wilson, Applewhite and Redlinger, 1949), there was considerable reduction of *Aedes* mosquitoes but the landing rate returned to its former level 24 hr. later. In the experiments described in this paper, with the Bes-Kil model which differs from the Besler generators previously tested in that the insecticide does not pass through the steam coils, the average reductions for an expenditure of 0.34 lb. per 100 yd. over woodland are 80 per cent at 100 yd., 27 per cent at 200 yd. and negligible reduction beyond that distance.

The Microsol (Hession) generator has been tested in Alaska at approximate expenditures of 1 to 5 lb. of DDT per 100 yd. of frontage; the treated area showed no reduction of mosquitoes when examined the following day (Wilson, Applewhite and Redlinger, 1949). The two experiments performed in Ontario woodland reported in this paper gave, with an expenditure of 0.3 lb. per 100 yd., 85 per cent reduction at 50 yd., 77 per cent at 100 yd., 71 per cent at 200 yd., 58 per cent at 250 yd., and no reduction beyond that distance. These results make it clear why the Alaska workers did not observe any reduction in the vast open areas into which they were emitting insecticide with this short-range machine.

The Dyna-Fog generator has been tested in Alaska (McDuffie *et al.*, 1950) in open spruce forest. With 20 per cent DDT solution applied at 0.47 lb. per 100 yd., the reduction in the first 200 yd. downwind was 95 per cent 3 hr. after application, falling to 63 per cent 12 hr. after application. With 10 per cent solution applied at 0.23 lb. per 100 yd. the reduction in the first 200 yd. downwind was 99 per cent 3 hr. later; 12 hr. after the application the average reduction in the first 200 yd. was 84 per cent, and in the next 100 yd. downwind it was only 24 per cent. In the experiments reported here, the immediate average reductions after applications that averaged 0.42 lb. per 100 yd. were 99 per cent at 100 yd., 85 per cent at 200 yd., 80 per cent at 300 yd. and 74 per cent at 400 yd. downwind.

The recoveries of DDT by the Schechter-Haller method allow comparisons to be made between the percentage reduction in the landing rate of mosquitoes and the amount of DDT reaching various distances downwind. For example, at a distance of 400 yd. downwind of the TIFA machine, in woodland, the average reduction was 58 per cent, and the recovery of DDT at that distance was 43 micrograms for the 81-sq.-in. screen, equivalent to 77 micrograms per sq. ft.

With the Dyna-Fog, at a distance of 400 yd., an average reduction of 74 per cent in landing rate was paralleled by a DDT recovery of 27 micrograms per sq. ft. These figures may be compared with those obtained for the actual mortality of *A. aegypti* exposed to an aerosol of oil containing 5.8 per cent DDT moving at 2 m.p.h. through a wind tunnel; these were 15 per cent for a passage of 175 micrograms of DDT per sq. ft., and 49 per cent for a passage of 5900 micrograms per sq. ft.

The results of the present investigation may also be considered with reference to the *Ct* (concentration *C* in mgm. per cu. m. of air, multiplied by time of exposure *t* in minutes) of the DDT in the aerosol expressed in mg.-min./m^3. With the wind moving through the 81-sq.-in. screens at 1 m.p.h., a median figure for the conditions in woodland, the volume of air sampled is 1.4 cu. m. per min. If it is assumed that the aerosol cloud took 1 min. to complete its passage through this point, the *Ct* is $0.043 \div 1.4 = 0.03$ mg.-min./m^3. This figure would be identical if, instead, a time of passage of 2 min. was assumed. Similarly, the *Ct* for the DDT in the aerosol for the Dyna-Fog at 400 yd. is 0.01 mg.-min./m^3. On the other hand, the *Ct* required to produce mortality of 50 per cent *A. aegypti* exposed to a settling aerosol containing 8 per cent DDT in oil (LaMer *et al.*, 1947) was as much as 140 mg.-min./m^3.

In interpreting these results it should be remembered that the recoveries obtained by the screens were probably low, and may be as little as one-sixth of those obtainable by a direct air-trapping method such as by the cascade impactor. But even then there still remains a large discrepancy between the dosage sufficient to give a reduction in landing rate in the field and that required to produce mortality as indicated by laboratory experiments. In fact, the workers in Alaska observed that after passage of a DDT aerosol cloud the mosquitoes would gradually reappear about their feet, and after some hours would reach higher levels. Further investigation is needed on this point. Certainly the aerosols used in this investigation had no discernible effect on flying anthomyiids, tachinids, tabanids, tipulids, Neuroptera, Odonata, and Hymenoptera.

SUMMARY: Assessments were made of the performance of 5 machines in producing aerosols from oil solutions of DDT for control of adult *Aedes* mosquitoes. When 5 per cent DDT in kerosene was emitted at approximately 20 g.p.h., the mass median diameter of the droplet spectrum produced by the Microsol generator was 90 microns; by the Husman sprayer, 40 microns; by the TIFA, 17 microns; and by the Dyna-Fog generator, approximately 5 microns. With the Bes-Kil generator the minimum emission rate was 40 g.p.h. and the resulting mass median diameter was 30 microns.

The Microsol generator is therefore not an aerosol machine and its effectiveness did not extend beyond 200 yd. downwind. The Husman sprayer was effective for distances up to 400 yd. in open woodland but not in dense woods. The Bes-Kil generator gave poor results in dense woods despite its high emission rate of aerosol droplets. Both the TIFA machine and the Dyna-Fog were effective in reducing the landing rates of *Aedes* mosquitoes at distances up to 400 yd. through dense woods.

At average dosages of 0.35 lb. of DDT emitted per 100 yd. of frontage, the average percentage reductions for the TIFA and the Dyna-Fog were, respectively, 89 and 91 at 200 yd., 77 and 80 at 300 yd., and 58 and 74 at 400 yd. downwind. Of the 5 machines only these two gave significant dosages of DDT at distances of 300 and 400 yd. in woodland.

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