ARTICLES

METHODS OF ASSESSING DROPLET SIZE OF INSECTICIDAL SPRAYS AND FOGS[1]

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Owing to the influence of size of spray droplets on their behavior, distribution and deposit on insect or target areas, accurate knowledge of the droplet size is an important consideration in the proper use of insecticidal sprays. Recent trends toward use of greatly reduced volumes have brought this requirement into sharp focus, for the smaller volumes require larger numbers of smaller size droplets for effective coverage, and smaller droplets are influenced much more than larger ones by wind, temperature, and other natural factors. Thus, it becomes increasingly important to sample and measure spray droplets accurately if we are to understand results and make progress in the technology of applying insecticidal sprays. The purpose of this paper is to discuss in one place the various methods currently in use for this purpose. For a more critical examination of the problems involved in the collection and behavior of particulate matter, the reader is referred to books by Cadle (1955 and 1965), Dallavalle (1948), Davies (1966), Fuks (1955) and Green and Lane (1957).

SAMPLING

Most insecticidal aerosols or sprays contain droplets of a wide range in size. Since it is not practicable to measure the size of each drop produced, a sample must be taken to determine the parameters of the entire droplet distribution. This sample is the first and most important element in determining the size and spectrum of spray droplets. The accuracy of the calculated statistical diameters and the conclusions that are drawn are dependent upon obtaining a sample that is representative of all droplets produced.

Obtaining a representative sample requires some knowledge of the droplet sizes produced by a particular operation so that appropriate sampling techniques may be applied. Shown in Table 1 are the representative sizes of various particles and the effective size ranges of several sampling and magnification devices. As an example, it is obvious that the entire spectrum of droplets produced by low volume sprays cannot be sampled efficiently on dyed cards. This is because these sprays may contain substantial numbers of droplets 5 to 10 microns (μ) or less which are difficult, if not impossible, to distinguish from spots or imperfections on the dyed paper.

A knowledge of the dynamics of small droplets is also necessary in obtaining a representative sample. Shown in Table 2 is the theoretical number of droplets per square inch deposited from a spray discharged at one fluid ounce per acre. Although these figures could not be obtained in practice due to many obvious considerations, they do serve to emphasize that a 10-fold increase in droplet diameter is accompanied by a 1000-fold decrease in number of droplets. The second part of the table, dealing with the settling velocity of droplets, shows that with a 10-fold increase in size there is approximately a 100-fold increase in settling velocity. These data are for spherical droplets having a specific gravity of 1.0 and settling in still air at a temperature of 70° F. and are obviously not applicable to all situations but serve to emphasize the importance of droplet size on drift, particularly of aerial sprays.

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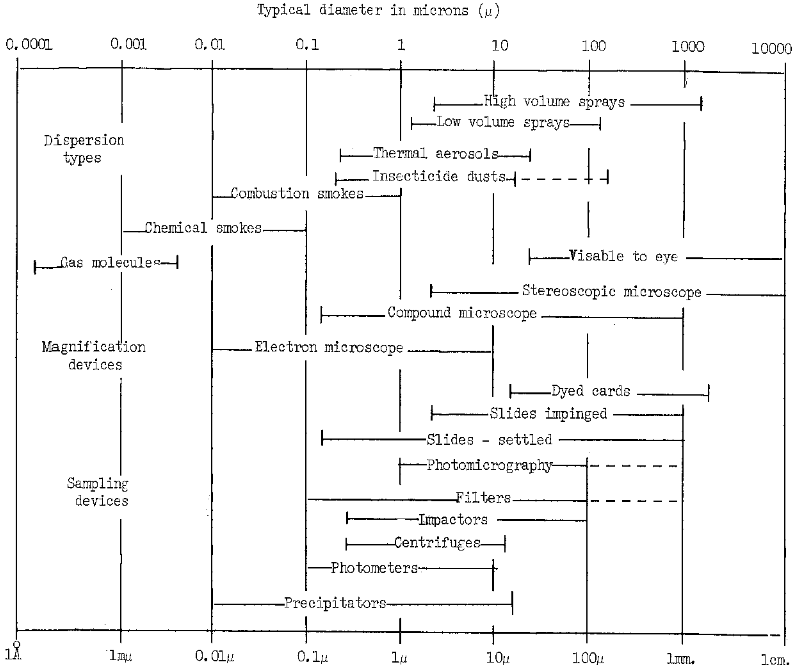
TABLE 1.—Representative sizes of various particles and the effective size of magnification and sampling devices used for their collection and measurement.



Also of great importance in obtaining a representative sample is the efficiency at which various size droplets are collected by the sampling technique used. Shown in Tables 3 and 4 are the efficiency of deposit of drops of various sizes and in different wind velocities on microscope slides and small diameter wires. It is evident from the data in Table 3 that only a very small percentage of droplets 10μ or smaller are deposited on microscope slides even in winds up to 20 miles per hour. These

TABLE 2.—The effect of size on the properties of liquid droplets.

Droplet diameter in microns	No. of droplets/sq. in. at 1 fl. oz./acre	Velocity of settling in ft./min.[1]
1	9,000,000	0.007 (approx. 1/128 in.)
2	1,100,000	0.024 (approx. ¼ in.)
4	140,000	0.095 (approx. 1 in.)
8	18,000	0.38
10	9,000	0.59
20	1,100	2.4
40	140	9.5
80	18	38
100	9.0	59
200	1.1	352
400	0.14	498

[1] From sampling Microbiological Aerosols, Public Health Monograph No. 60, 1959.

figures are also applicable to slides moved through the air at this velocity. A microscope slide waved at 3 ft. per sec. is approximately equal to a velocity of 2 m.p.h. Therefore, there is little deposit of droplets less than 10μ by this method.

The efficiency of deposit of droplets is also dependent upon the size of the collection surface. Thus, the use of small diameter wires offers a more efficient means of collecting small diameter droplets than microscope slides. As shown in Table 4, the efficiency of deposit of a 13μ droplet on a 0.25 mm. diameter wire is 73 percent in an 8 mile per hour wind. This is a considerably smaller droplet than can be effectively deposited on a 1 x 3 inch microscope slide as shown in Table 3.

TABLE 3.—Efficiency of deposit of particles impinged on a 1 x 3 inch microscope slide waved at various velocities.[1]

Droplet diameter in microns	Efficiency of deposit in percent at indicated velocity in mph		
	5	10	20
1	0.05	.1	.2
5	1.25	2.5	5
10	5	10	20
20	20	38	60
40	60	75	80
60	78	..	..

[1] From Yeomans, 1951, (based on data by W. Sell, Forschungaarb. ver. deut. Ing. (V.D.I.) Verlag No. 347, 1931).

EQUIPMENT FOR THE COLLECTION OF DROPLETS. All sampling methods have limitations on the maximum and minimum droplet size effectively sampled; therefore, the sampling technique to be used depends upon the size of droplet to be collected. The equipment commercially available for sampling liquid droplets is extensive and deals with the various physical properties of droplets. Thermal and electrostatic precipitators which collect particles by use of thermal gradients or the electrostatic charging of particles are very efficient for the collection of submicron to about 20μ particles. Both methods are prone to several errors, are complex, and require careful handling and are therefore not suited to use in the field. Centrifugal samplers are essentially air centrifuges which deposit particles by centrifugal force according to their size and most are acceptable for sampling particles from 0.5 to about 30μ. Filtration samplers impact particles of all sizes on fibrous filters. They have high collection efficiencies but usually are only adaptable to quantitive studies since droplets penetrate the fibers making microscope observation difficult. Widely used in atmospheric and clean room particle studies are forward scattering photometers. At present there

TABLE 4.—The efficiency of deposit of aerosols on wires at three wind velocities.[1]

Wind velocity in mph	Droplet diameter in microns	Efficiency of deposit in percent at indicated wire diameter in mm.			
		0.08	0.25	1.0	9.0
0.9	3.3	5.3	1.9	0.5	0.2
	7	34	18	8.8	1.4
	10	52	32	13	2.0
	15	75	50	25	4.3
3.0	3.7	34	20	8.4	0.7
	7.5	69	47	25	2.6
	13	89	69	40	7.6
	27	93	85	54	15
8.0	3.7	46	31	16	2.1
	7.5	65	57	42	11
	13	87	73	53	19
	27	100	84	64	28

[1] From Ranz and Wong, 1952.

are several manufacturers of this type of equipment. The forward scattering light principle is based upon the fact that at 90 degress the amplitude of the white light reflected from the surface of a particle is proportional to the square of the particle diameter. The equipment can be used to measure the size and number of particles as small as 0.1μ. The maximum useful size, however, is limited to droplets about 10μ because of deposition of the larger particles on the internal walls of the equipment. Photomicrographic techniques (Cadle and Wiggins, 1953; Rathburn and Miserocchi, 1967) which permit photographing solid or liquid particles 1 to 100μ suspended in air, are useful for size determinations of aerosols or sprays of a wider range in size than most techniques. However, they are suitable for use only in high concentrations of particles and at present no commercial equipment is available. More recently, laser holographic techniques (Roberts, *et al.*) have also shown promise.

The most widely used method for sampling droplets of the type used in insecticidal sprays and aerosols is by impaction. At present, several types of impactors are commercially available,[2] all of which sample droplets as small as 0.5μ. Shown in Table 5 are the air velocities and minimum droplet size sampled at each stage of a Casella cascade impactor. The upper size limit sampled is about 200μ; however, due to deposition on the orifice walls the usable upper size is limited to about 100μ. Cascade impactors are essentially a series of progressively smaller air jets which, because of the increase in air velocity and resultant droplet velocity from jet to jet, impinge successively smaller droplets at each jet. Droplets are collected on glass plates for microscopic examination of size and number. Shown in Figure 1 is a Casella cascade impactor and suction system for sampling airborne droplets, including the air tank, aspirator,[3] and flowmeter [4] used to provide air flow through the instrument.

TABLE 5.—Deposit of droplets by use of the cascade impactor.[1]

Impactor stage	Air velocity mph	Min. size deposited at 90 percent efficiency	Maximum size deposited
1	5	17.0	..
2	22	5.5	20
3	61	1.8	7
4	169	0.6	2.5

[1] From May, 1945.

Equipment using small diameter wires or rods rotating at high speeds are also available and are efficient for sampling insecticidal aerosols or sprays containing droplets smaller than 10μ.[5]

Other methods of sampling by impaction on glass slides include the use of wind tunnels and slide rotators (Figure 2). Although these are easy to use, the efficiency of deposit of droplets below about 10μ is low because of their low impaction velocity (Table 2). Droplets may also be impacted on stationary slides by wind or on hand-waved slides; however, the collection of the smaller droplets with these methods is also poor. Collection of droplets by gravitational impaction (settling) is one of the simplest and most effective sampling methods. Primarily a laboratory technique using settling chambers, it is also used extensively in the field to sample droplets of aerial sprays. In laboratory settling chambers, droplets of all sizes are collected with equal efficiency. In the field, however, the very small droplets, usually less than about 5μ, do not readily deposit by settling on horizontal surfaces, particularly on the ground, but tend to remain airborne. They may be carried out of the sampling area even under conditions of low wind velocity. Therefore, care must be taken that the in-

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[2] Casella, Mine Safety Appliance Co., Pittsburgh, Pa. Unico, Union Industrial Equipment Corp., Port Chester, N.Y. Anderson, Medi-Comp Research and Development, Salt Lake City, Utah.

[3] Union Industrial Equipment Corp., Port Chester, N.Y.

[4] F. W. Dwyer Mfg. Co., Michigan City, Ind.

[5] Rotorod Sampler, Metronics Associates, Inc., Palo Alto, Calif.

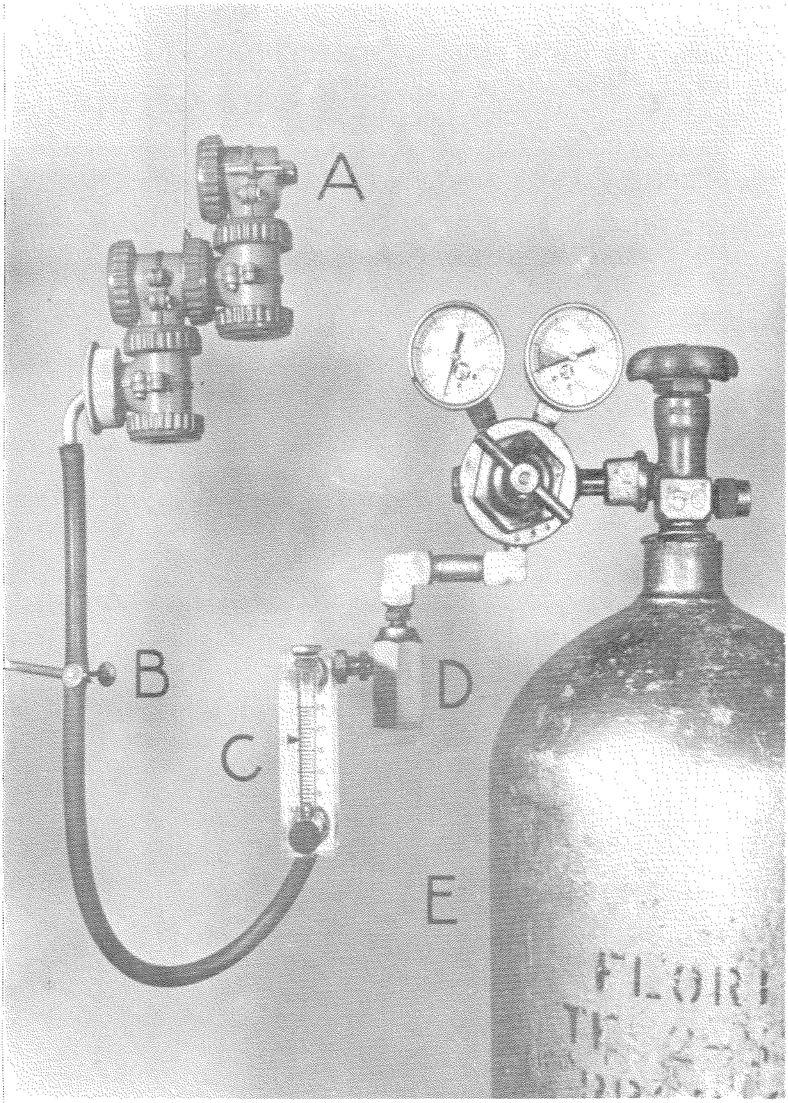

Fig. 1.—A Casella cascade impactor and suction system for sampling droplets; A—Impactor, B—Clamp or Casella valve for control of sampling time, C—Flowmeter for measuring airflows through impactor, D—Aspirator to provide suction.

ferences made do not exclude this possibility.

Slide coatings for collection and measurement of droplets. There are several coatings that may be applied to slides used for collecting droplets. Each has its advantages and disadvantages. Probably the most common is magnesium oxide, prepared by burning strip magnesium beneath a glass slide to form a white powdery coating on the slide, which should be slightly larger than the largest droplet to be collected. It has the advantage that the impressions of volatile droplets strik-

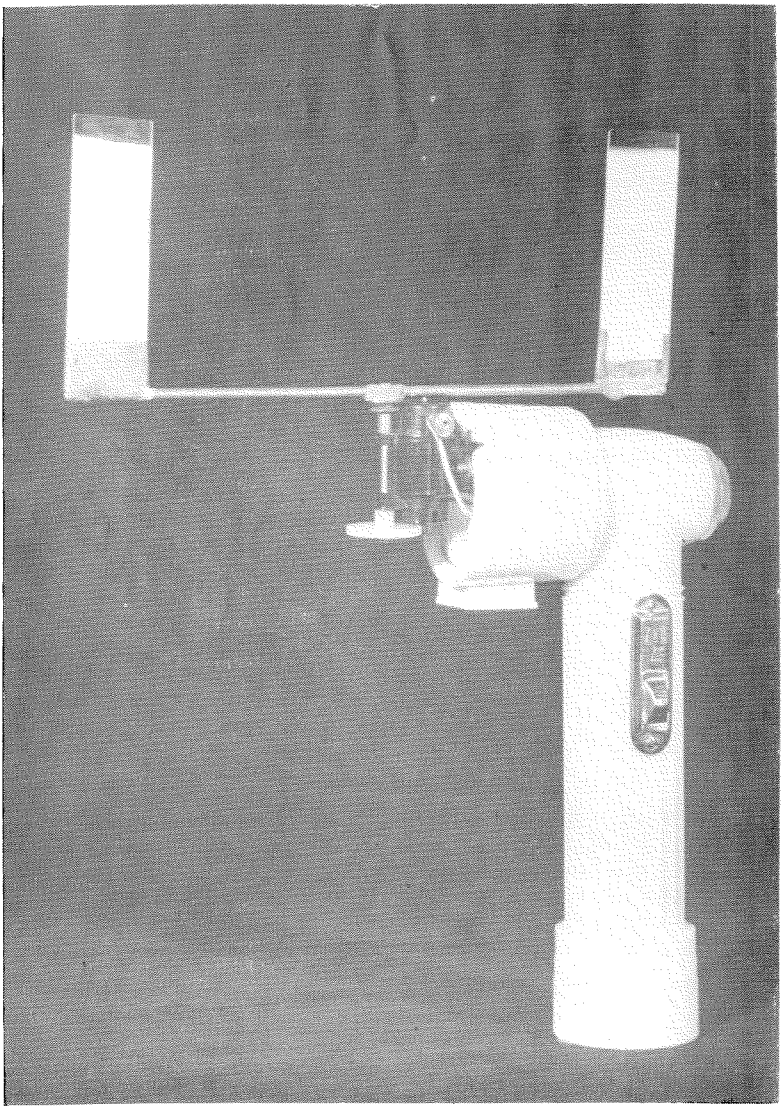

Fig. 2.—A battery powered slide rotator and magnesium oxide coated slides for sampling droplets.

ing the layer are retained as a permanent record of the droplets that made them. This method is useful only for droplets above about 5 microns in diameter due to the grain size of the coating and may not be used in the third and fourth stages of a cascade impactor because the jet of air destroys the coating. Since the impressions made in the soft layer are slightly larger than the droplets which made them it is necessary to apply a correction factor to the size of the crater formed to obtain the true drop size. According to May (1949), a factor of 0.86 should be applied to the size of the craters made by droplets above 20 microns. This factor decreases with drop size, being 0.80 for drops 15–20 microns and 0.75 for droplets of 10–15 microns. Below 10 microns there is no justification for a more precise measurement because of the increasing inaccuracy of measurement.

Another useful slide coating is Dri-film[6] (SC–87) a silicone liquid. Slides treated with this material can be used in impactors but if the droplets deposited are subject to evaporation the slides must be read immediately. The coating prevents the irregular spreading of droplets on the slide and the collected droplets appear as small spherical lenses.

To prepare the slides they must be first cleaned and dried. They are then dipped in a 10 percent solution of Dri-film in toluene, drained and dried at about 200° F for 30 minutes, after which they are dipped in acetone and dried. The slides may be used repeatedly by rinsing in acetone and polishing with lens paper. When the droplets no longer remain circular the slides should be recoated. Various other oleophobic coatings (Yeomans, 1949) may be used but generally are not as satisfactory as magnesium oxide or Dri-film.

When spherical droplets impinge on oleophobic slides, such as Dri-film, they spread and form convex lenses. Therefore, the diameter of droplets collected on this type of slide must be corrected for spread. The procedure for determining correction factors for spread of droplets on oleophobic slides as adapted from May (1945) and Yeomans (1949) is as follows: Using a compound microscope having a micrometer drum on the fine focus adjustment and using outside light from a flat mirror but without a condenser, focus on a droplet and measure and record the exact diameter. When in focus the boundary of a droplet appears as a ring which is alternately light and dark as small changes are made in the focus. Set the fine focus adjustment at zero and, using the coarse adjustment and the drop as a lens, focus on some object such as a window frame which is more than 2 feet away. Then using the fine focus adjustment, focus downward until the drop is again in clear focus. The reading on the fine focus adjustment is the focal length change. Divide the focal length change (f′) by the diameter of the droplet (2A) and compute the correction factor from Table 6. Multiply the diameter of the droplet by the correction factor to obtain the actual spherical size of the droplet. Determine correction factors for 10 to 20 droplets covering the size range of interest. New correction factors must be determined for any changes in formulation. For the correction factors shown in Table 6, the angle of contact of the liquid and the slide is assumed to be below 60° and the surface of the lens is assumed to be spherical. This is true for drops of most liquids. The correction factor will also vary with the refractive index of the liquid used. Since this is usually not known, but most often is

TABLE 6.—Correction factors for calculation of droplet spread on Dri-Film coated slides.[1]

$\frac{f'}{2A}$	Correction Factor	$\frac{f'}{2A}$	Correction Factor
1.5	0.58	2.6	0.43
1.55	0.56	3.0	0.41
1.6	0.54	3.5	0.39
1.7	0.52	4.0	0.37
1.8	0.50	5.0	0.35
1.9	0.48	6.0	0.33
2.0	0.47	8.0	0.31
2.2	0.45	10.0	0.29

[1] Adapted from May, 1945.

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[6] General Electric Co., Waterford, N.Y.

between 1.45 and 1.55, the correction factors shown in Table 5 for liquids of a refractive index of 1.5 are acceptable. May (1945) gives curves for computing the original drop diameter of liquids having refractive indexes between 1.2 and 1.7.

Other slide coatings often used include a matrix in which the droplets can be retained in their natural spherical shape (Hurtig and Perry, 1952). For oil droplets this can be a mixture of 3 grams of gelatin in 40 ml. of warm water to which is added 40 ml. of glycerine. About 2 drops of the warmed solution are placed on the glass slide and by means of a second slide, the drops are drawn out to form a thin film covering approximately two-thirds of the slide surface. After the drops are deposited several broken pieces of cover slip are placed on the slide to insure adequate space for the droplets to assume their spherical shape. Then a sufficient amount of the warmed mixture is added to a cover slip to form a pendant drop when inverted and the cover slip is lowered slowly until the drop touches the center of the sample and released. The slide is kept in a horizontal position until cool. Care must be taken not to trap small air bubbles in the matrix which might be mistaken for droplets.

Volatile droplets may also be sampled by coating the sampling slide with a stain which is soluble in the liquid to be sampled. For oil droplets, highly purified oil soluble stains are dissolved in acetone and applied as a thin film to a slide previously cleaned in hot chromic-sulphuric acid to insure an even coating.

Cards for collection and measurement of droplets. The use of cards dyed with an oil soluble dye or undyed cards with dyed spray solutions are widely used for the collection of spray droplets for assessment of coverage and droplet size, (Davis and Elliott, 1953; Thornton and Davis, 1956; Maksymiuk and Moore, 1962; Lee, 1964; Blinn and Lovell, 1965; Higgins, 1967; Skoog and Cowan, 1968; and others). The minimum drop size for which this method can be used is 10 to 20μ; however, the definition of the spot attained on the card depends greatly on the type of paper and dye used. Generally, a linear relationship between the diameter of the spot and the spherical diameter of the droplet occurs only above approximately 100μ. Below this size the relationship is curvilinear.

Depending upon the formulation and the type of dye and paper used, the relationship of the spot diameter to the spherical drop diameter will be about 2.5 to 3.5:1 for 25μ drops, 3.5 to 4.5:1 for 50μ drops, 4.5 to 5.5:1 for 100μ drops, and 5.5 to 6.5:1 for 200μ drops. For example, a 100μ droplet will make a spot about 0.5 mm. (500μ), a 50μ droplet will make a spot about 0.2 mm. (200μ), and a 25μ will make a spot only about 0.075 mm. (75μ). Therefore, some magnification will be necessary in order to measure or count the smaller spots. The effective use of this technique, however, is greatly dependent upon the spread of the droplet and calibrations must be made for each droplet size, insecticide formulation, type of paper, and the type of dye used. Kromekote cover 65 lb. paper glossy on one side has been shown to produce satisfactory results. It may be dyed with any oil soluble dye such as Sudan Black B, duPont oil red, etc. For oil red dyed cards the cards are dipped rapidly in a solution of 0.4 g./l. of duPont oil red dye in acetone, drained and allowed to dry before stacking. The cards must be kept separate after exposure to spray to prevent the drops deposited on one card from transferring to others. This is especially important for cards from which droplet size determinations are to be made. Several other satisfactory procedures for the preparation and use of dyed cards may be found in the literature (Davis and Elliott, 1953; Blinn and Lovell, 1965).

Because of the cost and possible staining of non-target objects with dyed spray solutions, the use of dyed cards is preferable to dyed spray solutions except for limited tests with low discharge volumes conducted in remote areas. Special techniques which depend upon a chemical reaction between the insecticide and the chemical impregnated in the paper cards are also available for at least one insecticide (naled, Koundakjain, 1965). This technique consists of dipping the card in a saturated solution of potassium iodide in methyl alcohol. Cards must be prepared under low light intensities and stored in manila envelopes to minimize paper discoloration.

The use of solid fluorescent particles (Himel, 1969) and thixotrophic solutions (Daum, 1968) for capturing and retaining liquid droplets are two more of the many techniques used to assess droplet size. The fluorescent particle method is based upon the uniform suspension of a known number of solid, insoluble, micron size zinc-cadmium sulfide particles in a known volume of non-volatile liquid. The size of the deposited droplet (for droplets larger than 10–20μ) is determined from the number of grouped fluorescent particles. By means of statistical techniques the numbers of droplets as small as 5μ in the spray may be calculated.

Thixotrophic solutions or solutions of a variable viscosity are employed to collect droplets of all sizes. The collected droplets are suspended in the matrix for microscopic examination.

The problems of collecting representative numbers of 5 to 10μ or smaller droplets with these techniques are similar to those experienced with slides or dyed cards. Therefore, care must be taken that the inferences made concerning droplet spectrum and size do not exclude the possibility that the spray may contain substantial numbers of small droplets which were not sampled.

MICROSCOPIC DETERMINATION OF DROPLET SIZE AND NUMBER

Because of the many different techniques involved in the treatment of samples obtained from various types of samplers, only the microscopic determination of the number and size of droplets as collected on glass slides by various methods will be considered.

CALCULATION OF NUMBER OF DROPLETS PER AREA. If it is desired to calculate the number of droplets collected per some unit of area, the length of each traverse made across the slide must be known. To facilitate this, stops on the mechanical stage which limit its travel between two previously determined points are desirable. By knowing the length and width of each traverse, the number of traverses, and the total number of droplets counted, it is simple to calculate the total number of droplets deposited per unit area. Also by knowing the volume of air sampled with the impactor or the swept area in the case of the rotator or hand-waving, a figure representative of the number of droplets per unit of volume in air may also be determined.

CALCULATION OF STATISTICAL DIAMETERS. The basis of all statistical parameters is the measurement of a sufficient number of droplets. A total of 200–300 droplets is generally accepted as a valid sample for determining the average droplet size of insecticidal sprays. The terms most useful in expressing the size of insecticidal aerosols and sprays are the arithmetic mean diameter, better known as the average diameter, the number median diameter (nmd) and the mass (or volume) median diameter (mmd or vmd). The average diameter is a mathematical expression derived from the number of droplets in each size (or size group); and is represented by the expression $\frac{\text{Snd;}}{\text{Sn}}$ where Snd is the sum of the products obtained by multiplying the number of droplets in each size by its corresponding size and Sn is the total number of droplets. The droplet spectrum is reported as the percent of the total number of droplets occurring in various representative size ranges and covering the entire size range sampled.

The nmd as shown in Table 7 is deter-

TABLE 7.—The calculations of average diameter, number median diameter, and mass median diameter for settled and impinged slides.

Ocular division	Droplet diameter in μ	No. of droplets	No. times diameter	Percent of total	Cumulative percent by number	Volume of droplet	No. times volume	Percent of total	Cumulative percent by volume
	d	n	nd			$d^3/1000$	$nd^3/1000$		
1	10	20	200	4	4	1	20	0	0
2	20	100	2000	40	44	8	800	17	17
3	30	50	1500	30	74	27	1350	29	46
4	40	20	800	16	90	64	1280	27	73
5	50	10	500	10	100	125	1250	27	100
		Sn=200	Snd=5000	100			$\frac{Snd^3}{1000}=4700$	100	

Avg. dia. $=\frac{Snd}{Sn}=\frac{5000}{200}=25\mu$

From Fig. 3. nmd—22μ, mmd—31μ

mined by multiplying the diameter by the number of droplets of that diameter and expressing each product as a percent of the total of all products. The cumulative percentages for each size are then ploted on logarithmic normal paper (No. 32,376; Codex Book Co., Norwood, Mass.), against the droplet diameter and the diameter at the 50 cumulative number percent is recorded as the nmd (Figure 3).

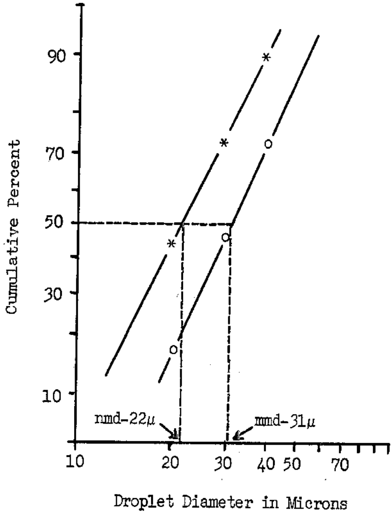

FIG. 3.—Determining nmd and mmd by direct plot.

In the example (Table 7), the droplets are measured to the nearest division of an ocular micrometer calibrated at 10μ per division at 100 x magnification, and correction for droplet spread was not considered.

The method used for determining mmd is dependent on the sampling method. The efficiency of collection of droplets by slide rotators, wind tunnels, and by handwaving increases directly with the square of the droplet diameter (d^2). The mmd, however, is computed on the basis of their volume, which is a ratio to the cube of the diameter (d^3). Therefore, according to Yeomans (1949) to compensate for the decrease in the rate of deposition as the droplet size decreases, the mmd is calculated on the basis of the droplet diameter, or d^3/d^2 or d. Thus, the number of droplets in each size is multiplied by only the first power of its diameter as a measure of the relative weight of the droplets in each size based upon the efficiency of deposit. This weighting of the droplets to compensate for the reduction in efficiency of deposit of the smaller droplets is satisfactory only if all droplet sizes produced are included in the sample, and may lead to serious errors in sprays containing significant numbers of droplets not included in the sample by reason of their low efficiency of deposit. The calculations for determining the mmd of droplets impinged on slides, therefore, are the same as those shown in Table 7 and Figure 3 for calculation of the nmd.

If droplets are collected by settling on slides, all droplets regardless of size are considered to be collected with equal efficiency; although, as previously stated, this may not be true under field conditions. Thus, the mmd is determined from the volume (or mass) of each droplet. The volume of a spherical droplet is equal to 11/6 times its diameter cubed. Since $\pi/6$ is a constant factor, it is sometimes omitted for ease of calculation and the cube of the diameter only is used. This gives a figure which is proportional to the volume or mass. These calculations also are shown in Table 7.

The mmd may also be calculated from the nmd by the following equation:

$$\log \text{mmd} = \log \text{nmd} + 6.098 \log^2 \sigma$$

where σ is equal to the size at 84.16 cumulative percent (35μ) divided by the size at 50 cumulative percent (22μ) as taken from the plot of the nmd in Figure 3. This results in a mmd of 38.9μ. With an ideal distribution and/or sampling, the calculated mmd would be the same as that obtained by direct plot. A pronounced difference indicates either a sample which is not completely representative of the distribution or a distribution which does not follow a normal probability distribution. (Note: Droplet data follow a Poisson distribution; therefore, the probability of the occurrence of a droplet of a particular size is not the same for all sizes as is the case with a normal or binomial distribution.)

The use of impactors requires a slightly different procedure for the calculation of an mmd from those previously described. Two hundred to 300 droplets are measured on the glass plate at each jet in the same manner as before. However, it is also necessary to compute the total number of droplets in each size range in the whole deposit. This is accomplished by measuring the length and width of the deposit on each slide and counting the number of droplets per traverse of known width taken across the width of the deposit. It is necessary, however, to count the droplets in several traverses so that a good estimate can be made of the average number of droplets per traverse. After the total number of droplets of each size at each jet has been determined, the figures are combined to give the total number of each size for all jets. After suitable corrections have been made to determine the original spherical size, the cumulative number or volume (mass) percent at each size is plotted against its corresponding size for determination of the nmd, vmd, or mmd. Droplet spectrum is reported as the cumulative weight percent of several representative sizes covering the entire size range sampled.

Bulk estimation of samples may also be used if the relative mass of the sample at each jet can be determined by chemical or colometric methods, since the average droplet size collected at each jet of a particular impactor is usually known or can be readily calculated.

Finally, it must be emphasized that replication is a major requirement in obtaining representative data. It is the investigator's tool for minimizing the effect of a single abnormal sample obtained by chance and must include all situations for which implications are to be made. Therefore, all situations which influence the production and collection of droplets, such as meteorological conditions, application techniques, insecticide formulations, and type of area should be noted and any conclusions drawn from the data acquired should be limited to these situations.

SUMMARY

It is evident from the preceding discussion that a thorough knowledge of the influence of the size of spray droplets on their behavior, distribution and deposit is necessary in order to effectively sample insecticidal aerosols and sprays. Since all sampling methods are limited in the maximum and minimum droplet size effectively sampled, it is important to select a method that will most adequately sample the entire range produced. Most insecticidal sprays contain droplets of a wide range in size—from less than 5μ to several hundred microns. Thus, the most useful equipment that is readily available at a moderate cost for sampling all droplets of this wide range are the cascade impactors and rotating wire samplers. The collection of droplets on microscope slides by settling or by hand-waving may be satisfactory if none or only a small percentage of the droplets are below 5μ. Since the droplets produced by thermal aerosols are primarily below 5μ, sampling methods for these droplets must be restricted to the use of the cascade impactors or other methods effective for sampling droplets of 1μ or less. Dyed cards or dyed spray solutions are useful only for sampling sprays having a minimum drop size of 10 to 20μ.

Dri-film and magnesium oxide are suitable oleophobic coatings for the collection of droplets on glass slides. For magnesium oxide coatings correction factors are available for determining true drop size. For Dri-film coatings, however, correction factors must be determined for each droplet size and each change in viscosity and refractive index of the spray solution. When sampling droplets of volatile liquids it may be necessary to use a water-glycerine-gelatin matrix to capture the droplets and prevent evaporation.

The methods used in the calculation of statistical diameters such as the mass median diameter (mmd) and the calculation of number per unit of area depend upon the methods used to collect the droplets. Droplet size reported as an average diameter, number median diameter, or mass (volume) median diameter should also include the droplet spectrum reported as the percent of the total number of droplets occurring in various representative size ranges covering the entire size range sampled.

Finally, the accuracy of the calculated diameters and the conclusions that are drawn from these figures are dependent upon obtaining a representative sample. Therefore, replication is necessary in order to determine that the sample taken is not an abnormal one or one that has been influenced by some unforeseen condition, and the sampling method or methods must collect representative numbers of all sizes of droplets in the spray being evaluated.

The purpose of this paper is to provide the reader with a basic knowledge of droplet sampling and size determination. It is hoped that simpler and more reliable field techniques will be developed in the near future; therefore, it would be advisable for those conducting research on droplet size to keep abreast of new advancements in this field.

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DAILY FLIGHT ACTIVITY OF *AEDES MELANIMON* DYAR (DIPTERA:CULICIDAE)

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Aedes melanimon Dyar is an important pest mosquito in the Central Valley of California. This species breeds in large numbers in seasonally flooded areas, such as in the duck clubs of the west side of the San Joaquin Valley; it is also found in irrigated pastures in association with *Aedes nigromaculis* (Ludlow). The dispersal of this species from breeding sites into residential areas is wellknown; it has been reported that this mosquito generally moves along waterways, with the prevailing winds (Kliewer and Miura 1969, Reed 1969). In order to understand the dispersal of *A. melanimon,* a study of the daily flight activity was made.

A study area was selected in the southern portion of the Grasslands Water District. It is located about midway and toward the western edge of the San Joaquin Valley. The surrounding land is generally level. About 5 miles westward there is an upward slope which extends to the foothills of the Coastal Range; the foothills of the Sierra Nevada Range lie about 35 miles to the northeast. The climate of the area is mild in the winter and dry and hot in the summer. The daily maximum temperature during the

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