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Evaluation of Spray Deposits from Low Volume Spray Nozzles

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SUMMARY

Spray deposit patterns of several low volume spray nozzles were evaluated. Fan spray, cone spray, and air atomizing nozzles were tested with each type operated at three pressures. The nozzles were tested at three speeds for each of the three pressures. The nozzle flow rate ranged from 0.4 to 2.5 gpa. The volume distribution evaluation procedure utilized a fluorescent tracer technique in which the deposit patterns from representative nozzles were collected and analyzed. Analyses were made by washing the fluorescent dye from the collection plates and determining the concentrations of the solution with a fluoro-microphotometer. The uniformity of the patterns was represented by a new parameter, coefficient of uniformity. This parameter is a transformation of the coefficient of variation and was used to standardize the uniformity of spray patterns within a range of 0 to 100 percent.

Droplet size distribution was measured for the cone, fan, and air nozzles using a photographic scanning technique. Dye deposits were collected on cards, and photographic negatives of the cards were produced. The negatives were scanned by the U. S. Department of Agriculture flying-spot particle analyzer to determine droplet frequency for 24 size classes and to determine the percent area covered.

To relate the spot size to droplet size, a droplet-forming mechanism was constructed which utilized a magnetic vibrating pump driven by an oscillator through a power amplifier. The uniform droplets produced by the mechanism were collected on cards and in oil cells and were accurately measured. The spread factor was determined for droplet sizes ranging from 93 to 1,000 microns in diameter when deposited on Lusterkote[1] cards and Scotchprint paper.

The results indicate that deposit patterns from fan spray and cone spray nozzles are more uniform when operating at 40 psi than at 25 or 30 psi. Pressure does not significantly affect the deposit patterns of the air nozzle. Speeds of 3, 4, and 5 mph do not significantly affect the deposit patterns of any of the nozzles tested.

The droplet size distribution did not vary significantly across the spray swath or with a change in speed for any of the nozzles tested. There was no significant difference in percent area covered for any combination of nozzle, pressure, or speed. The mass median diameter decreased with an increase in pressure, and the atomization for all the nozzles tested was very similar.

Since the spray distribution pattern data showed very high spray losses from the nozzles, we cannot say that the collected portion of spray is a random sample of what the nozzle produces. The data more closely represent what is deposited on the sprayed surface when operating the nozzle at a 19-inch height. Therefore, the conclusions from this study should be considered valid only for the evaluation of the atomized liquid collected on the spray surface rather than the atomization at the nozzle tip.

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[1] Trade names and firms are used in this paper solely for the purpose of providing specific information. Their mention does not constitute a guarantee or warranty of their products or an endorsement over other products not mentioned.

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Evaluation of Spray Deposits from Low Volume Spray Nozles

L. E. Bode, M. R. Gebhardt, and C. L. Day

INTRODUCTION

Interest in the deposit patterns and atomization of agricultural sprays has increased as a result of the development of equipment for applying low volumes of spray materials. Uniformity of application, droplet sizes, and spray losses are all important factors to consider when designing and developing equipment for low volume application.

Uniformity and completeness of coverage from atomized sprays are affected by the total number of droplets applied per unit area as well as by the size of the droplets. For a given rate of application and a uniform droplet size, the number of droplets available is inversely proportional to the cube of the droplet diameter. However, when developing equipment to produce small droplets in a uniform pattern, the factors of evaporation and drift must also be considered. Coarse atomization is attractive from the standpoint of evaporation and drift control, but adequate distribution is very difficult to achieve when droplet sizes are too great.

The uniform atomization required for low volume applications is ideally achieved by producing an atomized spray consisting of nearly uniform droplets large enough to minimize drifting but small enough to provide adequate coverage.

REVIEW OF LITERATURE

Techniques for applying low volumes of chemicals have greatly reduced spraying costs. Because low volume application of insecticides from aircraft has been successful (23) several researchers have become interested in equipment for applying low volumes using ground spray equipment.

Taft, *et al.* (30), developed an experimental device which utilizes a mist blower to drive mini-spin nozzles. A rotary disc, ultra low volume applicator is presently being developed by Burt (8). This device utilizes centrifugal force to atomize the chemical into desired particle size.

Spraying devices equipped with pneumatic nozzles are also being developed (16, 24). These devices are fitted with a small orifice which meters the liquid, and with an air jet which atomizes the spray material.

Evaluating Spray Distribution Patterns

The early methods of determining distribution were developed when DDT sprays were first applied for insect control. Glass slides laid across the spray swath were examined visually to determine whether or not adequate coverage had been obtained (18).

Patterson and Shanks (25) reconstructed the "Riley Sprayograph" and used a moving slit to sample the deposits. With the spray directed downward, the moving slit acts in the same manner as the slit in a focal plane camera shutter. An oil cell or paper placed under the slit would collect a sample of the instantaneous discharge of the nozzle.

The colorimetric or dye tracer method has become available because of the development of sensitive spectrophotometers. These instruments measure the intensity of light transmitted through a sample having a dye tracer. The major disadvantage of the dye tracer technique is the considerable time and personnel required to handle the sampling procedure. When spraying with ultra low volumes and evaluating drift, the dye tracers have insufficient sensitivity. Yates and Akesson (34) found that fluorescent tracers offered the necessary sensitivity for quantitative microresidue analysis.

Evaluating Spray Atomization

The size of spray particles or the degree of spray atomization is expressed as mass median diameter (mmd). The mmd is the droplet diameter that separates the spray volume into two equal parts, half the volume in drops larger than this diameter and half in drops that are smaller.

Davis (10) collected samples of oil sprays on microscope slides coated with an oleophobic film. The slides were photographed and the spray drops on the slides measured and counted from a projection of the photographic negative.

Davis observed from his measurements that there seemed to be a relationship between mmd and diameter of the largest drop. Maksymiuk investigated this further and developed a "D-max" method of estimating mmd (20). D-max is the diameter of the largest spot which is not more than 200 microns larger than the next smaller spot, divided by a conversion factor.

Thorton and Davis (33) described a method for sampling which involves the selection at random of a small number of mmd determinations and the computation of the mean mmd.

Tate (31) determined droplet size by an immersion sampling technique wherein dyed water is sprayed into cells containing a hydrocarbon solvent. Using light transmitted through the glass bottom of the cell, the collected droplets were photographed on high contrast film. The photographs were scanned automatically in an electronic analyzer and the mmd was computed.

Determining Spread Factor

When droplets are sprayed on a deposit medium, they do not maintain their original diameter but spread out on the collection medium. This spread is usually expressed as the spread factor which is the ratio of the spot size to the droplet size. The spread factor is influenced by the surface tension of the fluid, the characteristics of the paper or deposit medium, the relative humidity of the ambient air, and other factors.

Many drop producing mechanisms have been developed that cause a continuous stream to break into droplets in a regular manner so that the spread factor can be determined. Mechanical vibration is often used to produce the drops. As the source of vibration, investigators have used tuning forks, modified earphones, loudspeaker mechanisms, and piezoelectric crystals (3).

Davis (11) used a 6-volt electromagnet to vibrate a blade having a needle-point end. Liquid forced out of a capillary contacted the vibrating needle and was separated into a succession of drops streaming in a single line. Experience with such a device revealed the extreme difficulty of obtaining reproducible sizes, and the streams were difficult to control.

An improved vibrating capillary device for producing uniform water droplets was developed in 1963 (21). It consists of a hypodermic needle vibrated at its resonant frequency by an electromagnetically driven diaphragm, and it produces streams of droplets with diameters down to 30 microns.

May (28) developed a method of determining the size of droplets using optical measurements. The drops are allowed to fall into a layer of magnesium oxide smoked onto a glass slide. Drop size is estimated by multiplying the optically measured diameters of the resulting craters by a factor involving the material's index of refraction.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Two methods of evaluating low volume nozzles were used in this study: (1) a fluorescent dye tracer method and (2) a photographic negative scanning analyzer technique.

The general procedure was to collect the deposit patterns from representative low volume nozzles and to analyze the collected samples. A spray stand was constructed to disperse the atomized liquid so that conditions could be reproduced for the agricultural nozzles tested. A fluorescent dye tracer was sprayed onto stainless steel collection plates that were placed across the spray swath. The dye was washed from the plates with a predetermined amount of water. The quantity of original dye that was on the plates was determined by analyzing the wash solution in a microphotometer.

With the same variables as were used in the fluorescent tracer technique, a carmine water soluble dye in the atomized spray was deposited on cards placed across the spray swath. Film negatives of the cards were prepared and analyzed on the flying-spot particle analyzer (FSPA) at Wooster, Ohio. The FSPA determined the particle size frequency distribution and area covered. To relate the spot size on the card to the actual drop size, a procedure was developed to determine the spread of the droplets when they were deposited on the cards.

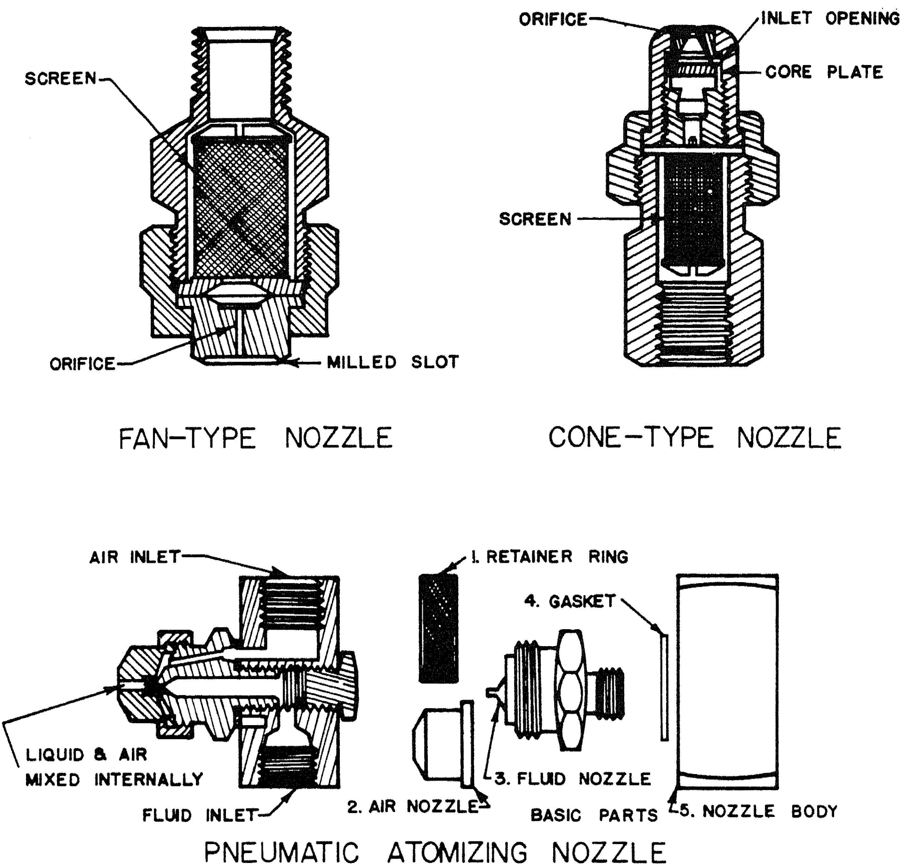

Fig. 1—Design features of spray nozzles.

Nozzles, Spray Stands, and Controls

Fan spray, cone spray, and pneumatic atomizing nozzles were tested with each type operated at three pressures. Three speeds were used at each of the three pressures. The nozzle flow rate ranged from 0.4 to 2.5 gpa. The study included fan spray nozzles 730039, 730023, and 650017; cone spray nozzle TX-1; and pneumatic atomizing setup F-1. All of the nozzles were manufactured by Spraying Systems Company. Distinctive design features of the spray nozzles are shown in Figure 1.

The spray stand shown in Figure 2 was designed and constructed so that identical conditions could exist for all the nozzles tested. To more closely simulate a field sprayer, the stand was designed to move the nozzle and keep the samples stationary. The nozzle height was adjusted by a variable height platform.

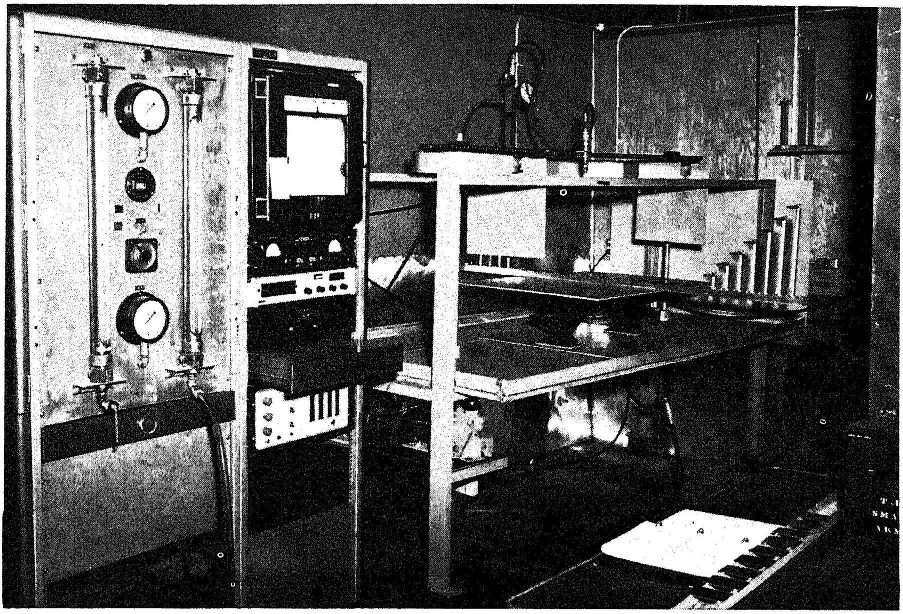

Fig. 2—A general view of the spray stand and control panel.

The control panel provided for the measurement of speed, pressure, flow, and temperature. The speed of the nozzle as it moved above and across the collection plates was controlled by a variable speed drive unit (Figure 3). The speed of the nozzle was continuously measured by the use of a tachometer transducer and a preset counter. The transducer develops a pulse, the frequency of which depends on the speed of the shaft rotation. The preset counter counts the number of pulses generated by the transducer in a given time period. The counter was equipped with a variable width gate which allowed variation of the time period for the gate to be open. The frequency can be displayed in any units desired by selecting the correct conversion factor.

Spread Factor Equipment

The spread factor for various size droplets on Lusterkote cards and Scotchprint paper was obtained by producing a stream of uniform droplets and accurately measuring the droplets when deposited in an oil cell and on the paper.

The method for producing uniform droplets reported by Atkinson and Miller (3) was adapted to this study. Figure 4 shows a block diagram of the electrical and liquid flow path for the apparatus that was used. A view of the droplet forming mechanism is shown in Figure 5. The procedure utilized a magnetic vibrating pump unit that was driven by an oscillator through a power amplifier. The amplifier was used since the output of the oscillator was of insuf-

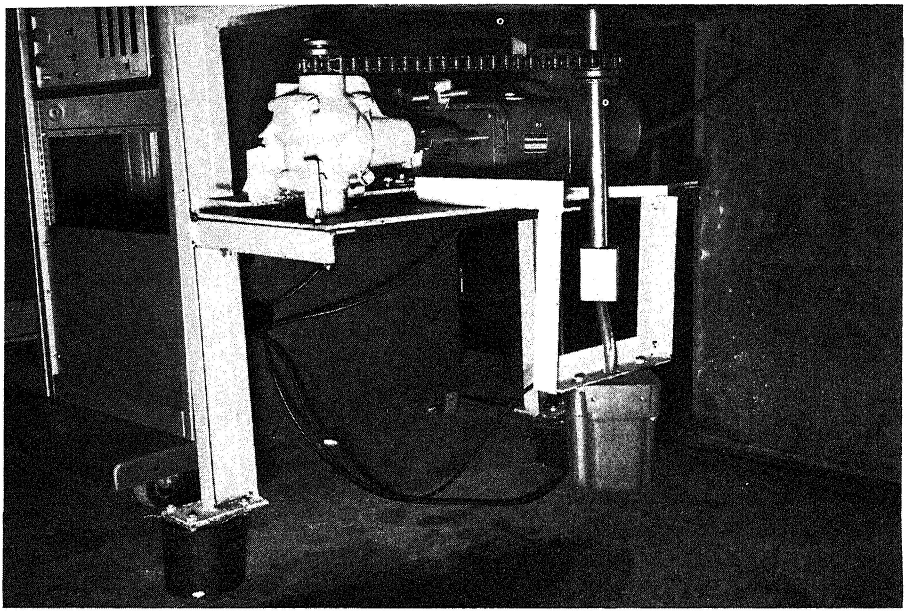

Fig. 3—The variable speed drive unit and tachometer transducer that regulated and measured the nozzle speed.

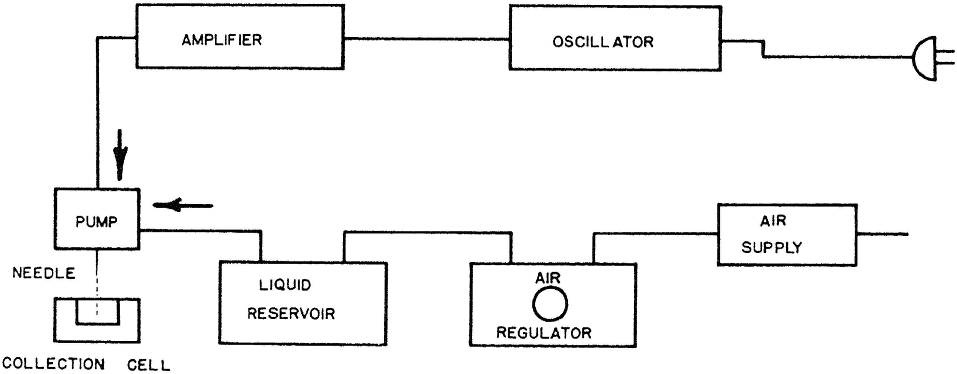

Fig. 4—Block diagram of electrical and liquid flow path.

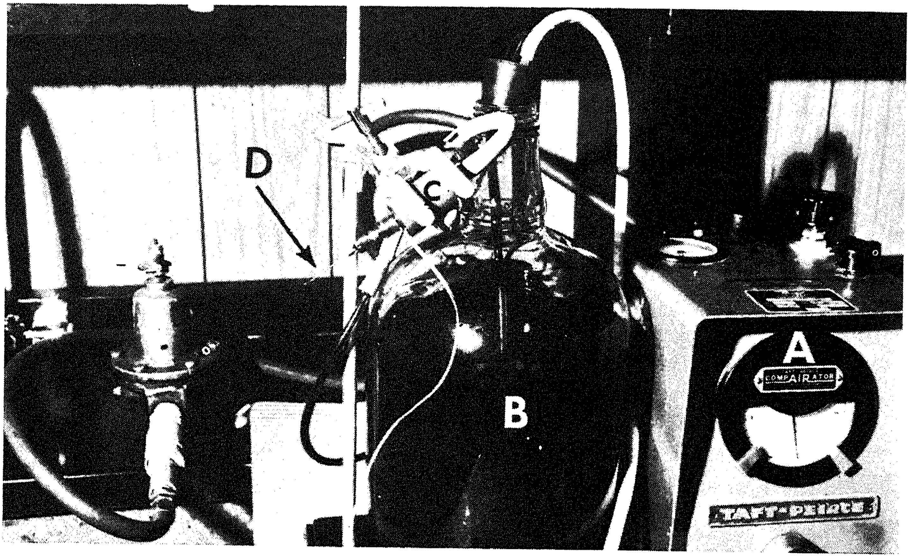

Fig. 5—Close-up view of precision regulator (A), fluid reservoir (B), and pump (C) with hypodermic needle (D).

ficient amplitude to drive the pump unit. The magnetic pump caused the stream of water from a hypodermic needle to be broken into uniform particles, the sizes of which are a function of the frequency of vibration. The frequency of vibration could be varied by changing the output of the oscillator. A precision regulator was used to control the pressure of the air above a reservoir of fluid and regulate the flow rate.

By using various combinations of needles, excitation amplitudes, flow rates, and frequencies, various size droplets were produced. Best results were obtained from the system when the amplitude of the amplifier output was adjusted for 24 volts at 60 cps. The frequency was then adjusted for optimum results using different flow rates and needle sizes. To obtain 500-micron droplets, the frequency was adjusted to 760 cps and a size 26 needle was used. For 300-micron droplets, the frequency was adjusted to 1,100 cps and a size 27 needle was used. In order to obtain droplets smaller than 200 microns in diameter, static electricity was used to pull small satellite streams of droplets from the mainstream. In this manner small 30- to 50-micron droplets could be made.

The collecting cell was constructed from plexiglass material. The cell contained two oil layers that were immiscible and had the upper and lower layers less than and greater than, respectively, the specific gravity of the atomized liquid. The water droplets would then stay at the interface of the two oils rather than fall to the bottom of the cell where they would tend to flatten out. Duo-Seal pump oil, manufactured by Welch Scientific Company, and kerosene were the two oils used in this study.

The droplet size and spot size were determined by moving the oil cell and paper through the stream simultaneously and then measuring the corrected droplets with a calibrated microscope. Data were taken for two types of paper. Droplets on the Lusterkote cards penetrated into the card, leaving a spot of dye which could be measured; while the Scotchprint paper was impermeable to liquid. The drops remained suspended on the Scotchprint paper until they evaporated, leaving a dye stain.

Fluorescent Tracer Equipment and Procedure

To determine the spray distribution patterns from the nozzles, a fluorescent tracer technique was used. A colorimetric method was developed and tried but proved unsuccessful due to inadequate sensitivity when spraying low volumes. When the dye concentration was increased to gain sensitivity at low volumes, all of the dye would not go into solution; therefore, the colorimetric technique was replaced by a fluorescent tracer technique. Because of the findings of Yates and Akesson (34), brilliant sulpho flavine was chosen as the fluorescent dye.

The laboratory analyses were made by preparing a standard curve from known concentrations and by referring unknown concentrations to the curve.

The Aminco fluoro-microphotometer, with a 405 primary filter, and a 2A-12 secondary filter, was utilized for measurement of the brilliant sulpho flavine samples. The six meter multiplier settings, .3, .1, .03, .01, .003, and .001, provided adequate sensitivity with a useful range of 2 parts per billion (ppb) to 5 parts per million (ppm) concentrations. Samples above 20 ppm could not be analyzed because the curve was not linear above this level. Samples were always measured on the most sensitive range without exceeding the 100 scale divisions available. The concentrations were obtained from calibrations with known standard solutions. Figure 6 shows the curve for the .3 multiplier setting. Accuracy of the measurements was determined from a statistical analysis of the calibration data. A linear regression line was fitted to the calibration data by the conventional method of least squares. The estimated regression line for the .3 multiplier range was calculated as $\text{ppm} = -0.3333333 + .0002777778T$. The standard error of estimation was zero when calculated to eight decimal place accuracy.

A similar analysis was made for all ranges (Table 1). All the ranges produced a linear response, and the fluorescent concentrations for all samples were computed from the appropriate calibration equation. To keep in the linear range, two concentrations of dye were used. A dye concentration of 5,500 ppm was used to test the fan and cone nozzles, and an 8,000 ppm concentration was used for the air atomizing nozzles. The samples were collected on 2 by 3 inch stainless steel plates. Twelve plates were placed across the spray swath on 3-inch centers. After spraying, the plates were washed until exactly 10 grams of wash solution had been collected. A Sartorius balance with a least count of 0.1 grams was used to weigh the wash solution. Recovery from the wash procedure was tested and found to be about 95 percent.

TABLE 1--EQUATIONS FOR STANDARD CURVE

Meter Multiplier Setting (mms)	Equation T = % transmittancy x mms	Correlation Coefficient	Standard Error of Estimation	Minimum T Value*
.3	- 0.333333 + 0.000277 x T	.99999	0.0	10,000
.1	- 0.050237 + 0.000249 x T	.99975	0.00994	3,000
.03	- 0.027614 + 0.000251 x T	.99878	0.00807	1,000
.01	- 0.012742 + 0.000250 x T	.99879	0.00235	300
.003	- 0.003738 + 0.000225 x T	.99897	0.00111	100
.001	- 0.004282 + 0.000236 x T	.99350	0.00143	0

* The indicated equation was used when the T value was above the value in this column.

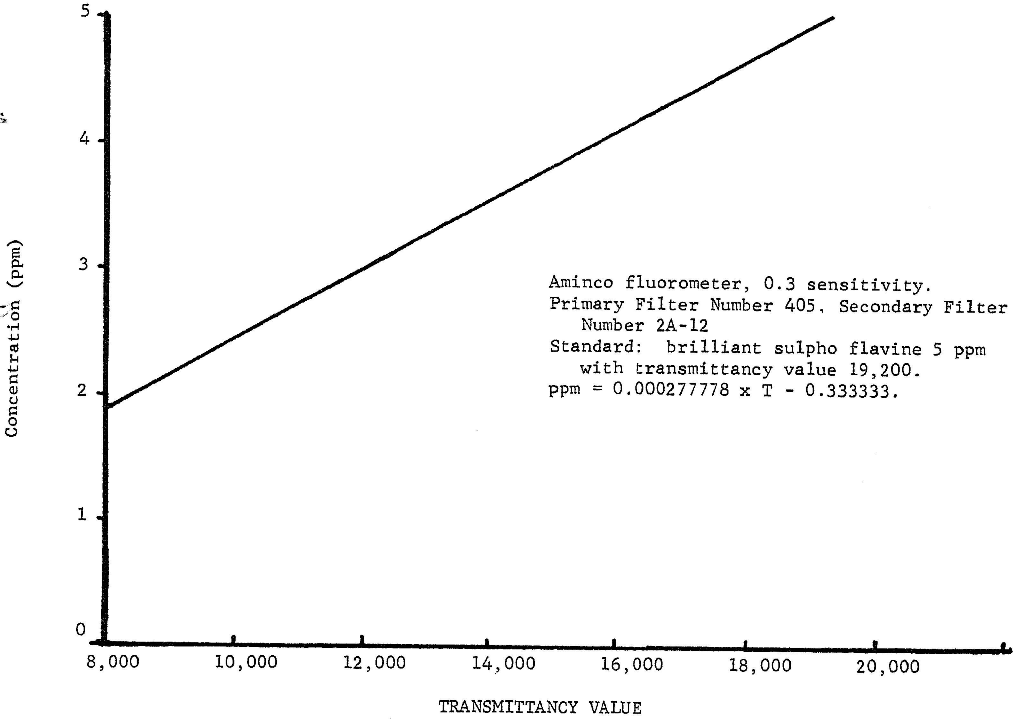

Fig. 6—Calibration curve for brilliant sulpho flavine.

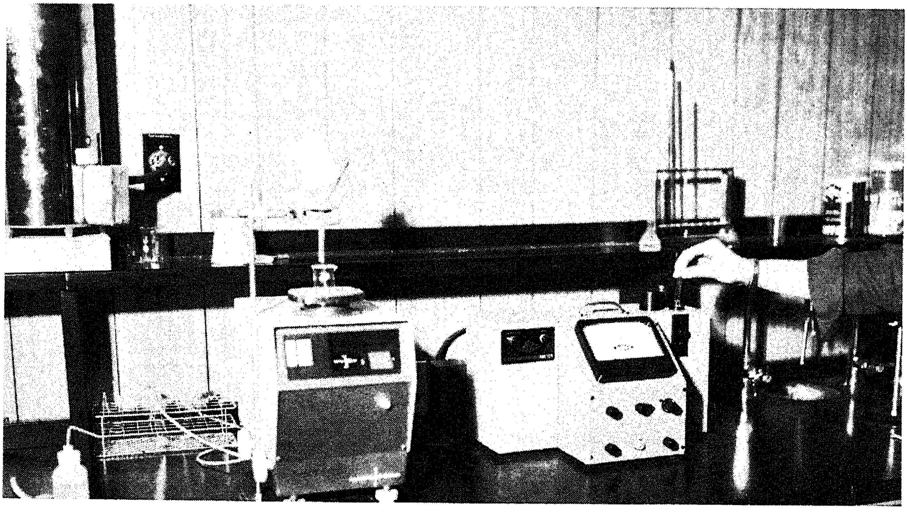

Fig. 7—Amino fluoro-microphotometer used to measure the dye concentrations.

The wash solution was placed in an Aminco fluoro-microphotometer for the determination of original dye on the plates (Figure 7). The fluoro-microphotometer is a direct reading filter fluorometer that permits rapid, routine, quantitative analysis of compounds with known excitation and emission spectra. The unit is characterized by its high sensitivity and linear response.

Flying-Spot Particle Analyzer

The particle size frequency distribution and area covered were analyzed on the FSPA at Wooster, Ohio.

The U. S. Department of Agriculture FSPA (Figure 8) performs its functions through analysis of negative photomicrographs of particles made on 35 millimeter film (6). The image analysis system converts an optical image to an electrical, time-varying function by means of an scanning process. The image plane scanning used in the FSPA is accomplished by a moving spot of light generated by a cathode-ray tube which explores the negative. Image measurements are made by operating on a video signal subsequently generated from the scanning signal.

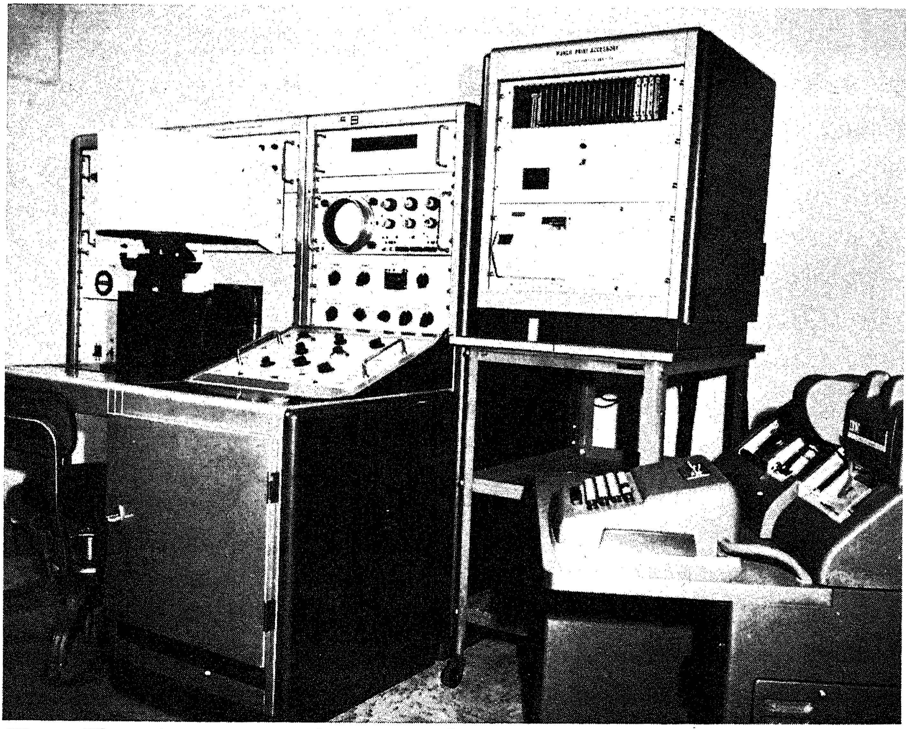

Fig. 8—The U. S. Department of Agriculture flying-spot particle analyzer.

The accuracy of the FSPA is in direct relationship to the sampling techniques. Sharp contrast is required on the negative for the analyzer to distinguish a small particle. Also, the droplet population must be large enough to minimize the boundary error. Processed photographic paper was used in this study, and by using a red dye in the atomized liquid sufficient photographic contrast was obtained.

The first samples were sprayed on Lusterkote cards using a nigrosine black dye in water solution. When the cards were photographed, it was discovered that the dye left a black ring around the edge of the droplet and that there was insufficient dye in the center to give good contrast. A carmine water soluble dye was then used and found to give good contrast for all droplet sizes.

On the basis of the above results, a carmine dye solution was selected for this study. It was sprayed on Scotchprint cards and Lusterkote paper. The cards and paper were 2 by 3 inches, and six cards were placed across the spray swath on 3- inch centers.

The droplets from the large nozzles ran together when collected on Lusterkote cards but remained distinct and independent on Scotchprint paper which has a smaller spread factor. However, when low volumes were sprayed on the Scotchprint paper, the extremely small droplets could not be distinguished; so Lusterkote cards were used to collect these samples. Therefore, spray volumes below 1 gpa were collected on Lusterkote cards, and volumes greater than 1 gpa were collected on Scotchprint paper.

The negatives were prepared with a plate camera at the Technical Education Services, University of Missouri. The Scotchprint paper was enlarged 2½ times, and the Lusterkote cards were taken at a direct 1 to 1 ratio. Several sample cards were mounted together, and 11 by 14 inch negatives were made. Thirty-five millimeter strips of the film were cut for each sample, and 350 negatives were analyzed on the FSPA. For each negative the frequency of droplets in twenty-five classes, the total number of droplets, the boundary count, and the area covered were determined and recorded on IBM cards.

RESULTS

Results of Fluorescent Data

The most desirable spray distribution from a field sprayer is a pattern which results in the spray material being uniformly distributed over the entire surface to be sprayed. The air atomizing and cone nozzles were designed to give a uniform distribution when used individually. Fan nozzles, however, were designed to have a tapered edge pattern so that overlapping of the individual patterns produced the uniform pattern. To compensate for overlapping, adjacent nozzles were assumed to be on 20-inch centers and to have spray patterns identical to the one under test. Resulting application rates in the overlap area were superimposed to determine the total rate of application in the area. The overall spray pattern was analyzed and compared with the patterns from the individual nozzles. To be able to compare the patterns, it was desirable to express the uniformity as a single number.

A new parameter, coefficient of uniformity, was used to describe the uniformity of the spray patterns. The parameter is a transformation of the coefficient of variation and was developed from an adaptation of the relative variance as presented by Porterfield (26) in describing the seed distribution from a row planter.

The coefficient of uniformity (C.U.) is derived from the assumptions that the worst possible spray pattern exists when all of the spray is deposited on one point and that the best possible pattern exists when the deposit area has the same concentration on all points.

By definition

$$C.U. = \left[\frac{S_{max} - S_{observed}}{S_{max}} \right] 100$$

It can be shown that the maximum standard deviation is the mean concentration multiplied by the square root of the sample size.

$$S_{max} = \overline{X} \sqrt{N}$$

The minimum value of C.U. occurs when the observed standard deviation is the largest.

$$C.U._{min} = \left[\frac{\overline{X}\sqrt{N} - S_{observed}}{\overline{X}\sqrt{N}} \right] 100 = \left[\frac{\overline{X}\sqrt{N} - \overline{X}\sqrt{N}}{\overline{X}\sqrt{N}} \right] 100 = 0\%$$

The maximum value of C.U. occurs when the observed standard deviation of the deposits is zero.

$$C.U._{max} = \left[\frac{\overline{X}\sqrt{N} - O}{\overline{X}\sqrt{N}} \right] 100 = 100\%$$

Therefore, C.U. is zero percent when the worst possible distribution exists and is 100 percent when the distribution is the best. When comparing the patterns of different spray nozzles, the range of C.U. values is from 0 to 100 percent regardless of the number of plates or sample points involved.

An analysis of variance was computed for the concentration on each plate with compensation for overlapping effects. Sources containing significant differences were analyzed by Duncan's New Multiple Range Test at the 5 percent level to determine where the significant differences were.

The results of the test showed that speed did not influence the patterns for any nozzle type. The pressure, however, had a significant effect on the patterns from the fan type nozzles. Operating pressure of 40 psi resulted in much better spray patterns than operating pressures of 25 or 30 psi.

To relate the amount of spray material lost between the nozzle and collection plates, the percent spray loss was computed. The percent loss was calculated as the difference between the nozzle flow rate and mean concentration on the plates, divided by nozzle flow rate. The spray loss was due to drift, evaporation, edge effect, washing loss, and other factors. About 25 percent of the spray was lost from the fan nozzle 730039. For the smallest fan nozzle, tip number 650017, 40 to 50 percent of the spray was lost when the nozzle was operated at 25 and 30 psi. At 40 psi, however, the loss was decreased to about 25 percent. Figures 9 and 10 show typical spray patterns from the fan nozzles.

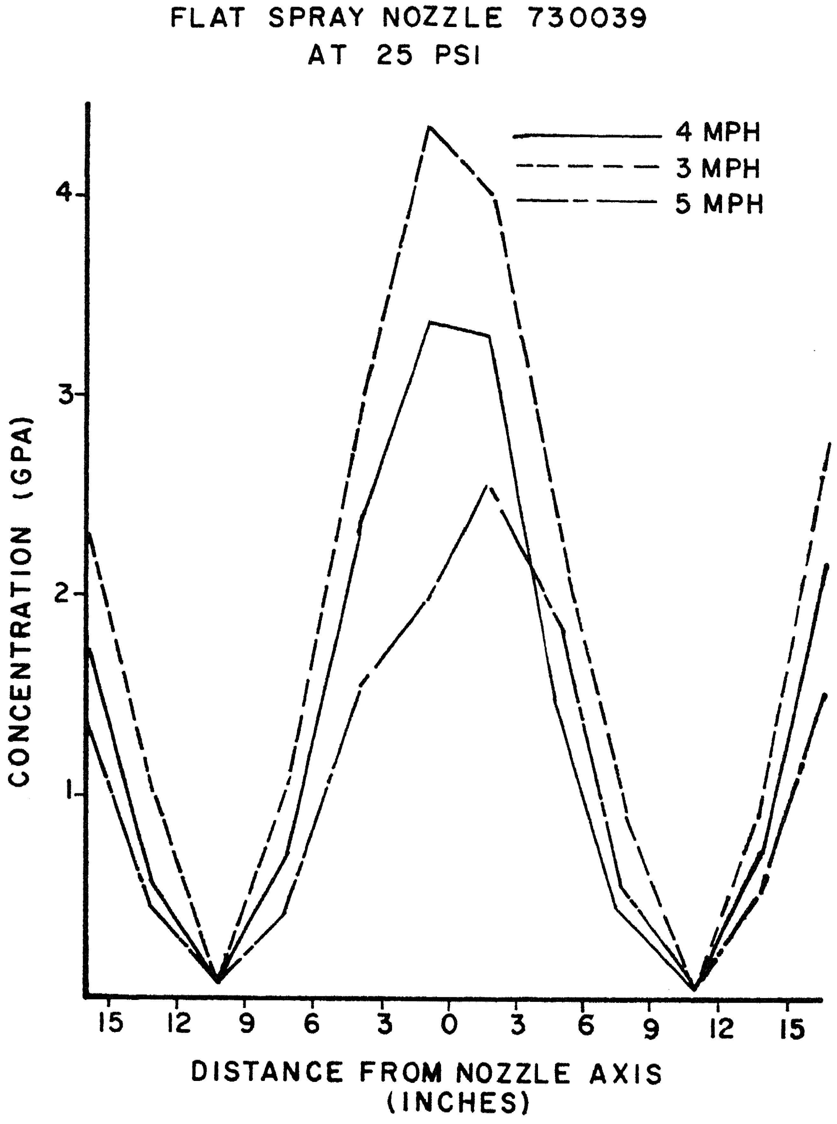

Fig. 9—Over-all spray pattern from flat spray nozzle tips 730039 at 25 psi for three speeds.

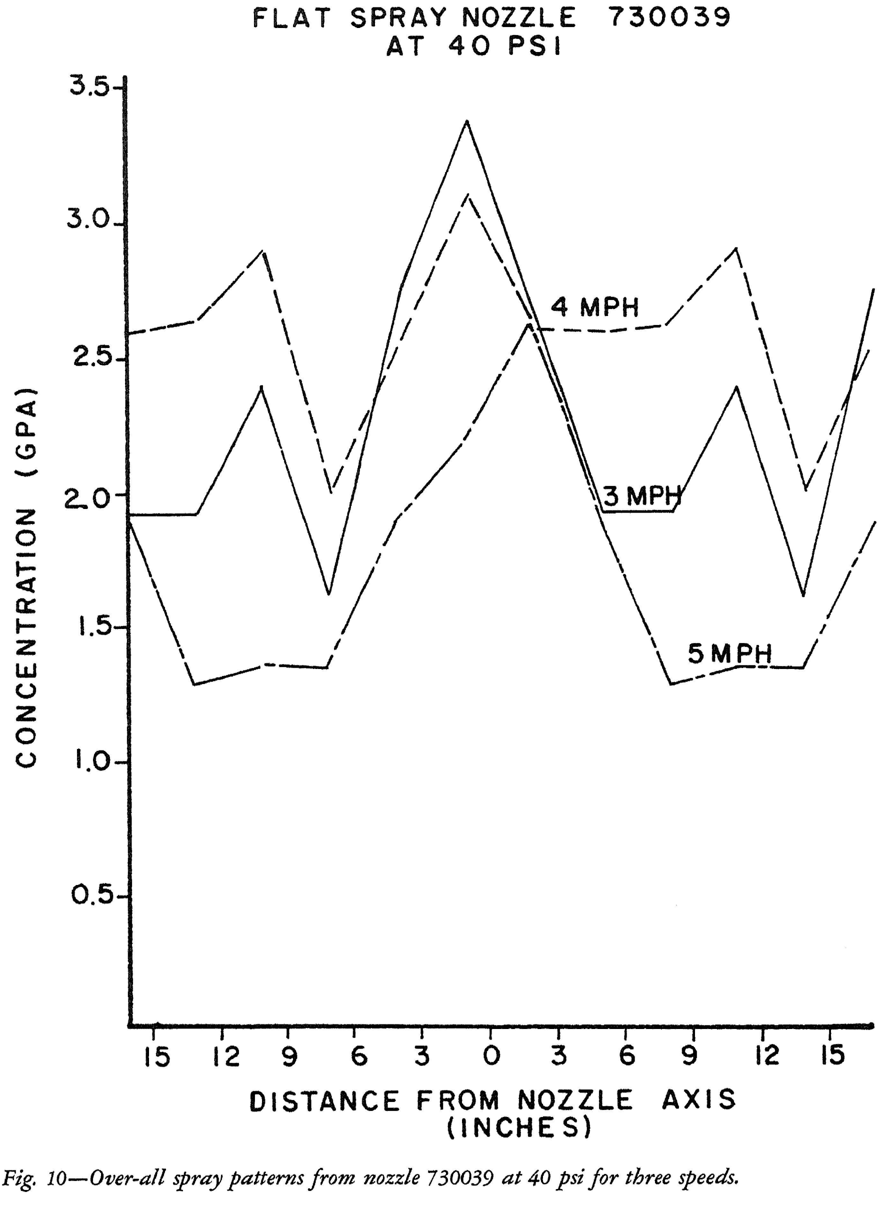

Fig. 10—Over-all spray patterns from nozzle 730039 at 40 psi for three speeds.

Results from cone spray nozzle TX-1 show that speed and pressure had a much smaller effect on its pattern than on those of the fan nozzles. The coefficients of uniformity are similar at all conditions of speed and pressure. The amount of spray loss was generally between 30 to 40 percent for all speeds and

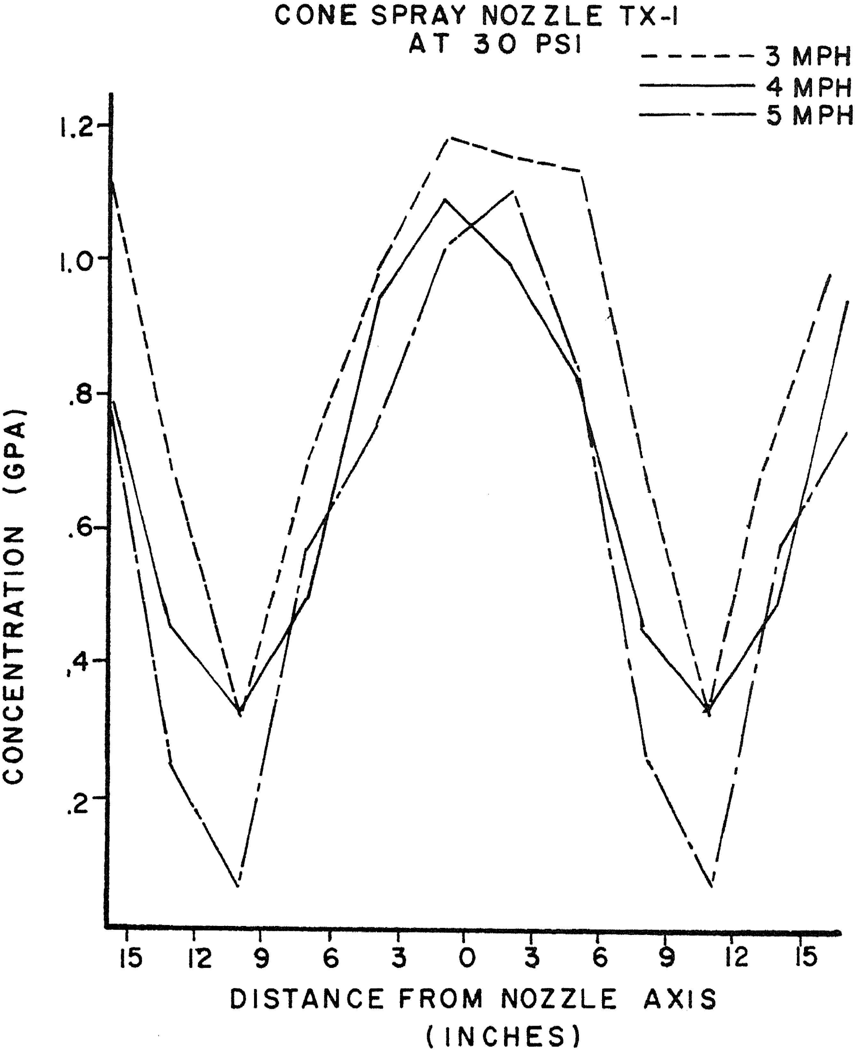

Fig. 11—Over-all spray patterns from cone spray nozzle TX-1 at 30 psi for three speeds.

pressures of the cone nozzle. Figure 11 shows distribution pattern from the TX nozzle at 30 psi.

Spray deposit patterns from the air atomizing nozzle were almost the same regardless of speed and pressure. The C.U. was greater than 90 percent in all cases. Spray loss was extremely large for the air nozzle, with less than 20 percent of the spray depositing on the collection plates. Figure 12 shows spray patterns from the air atomizing nozzle.

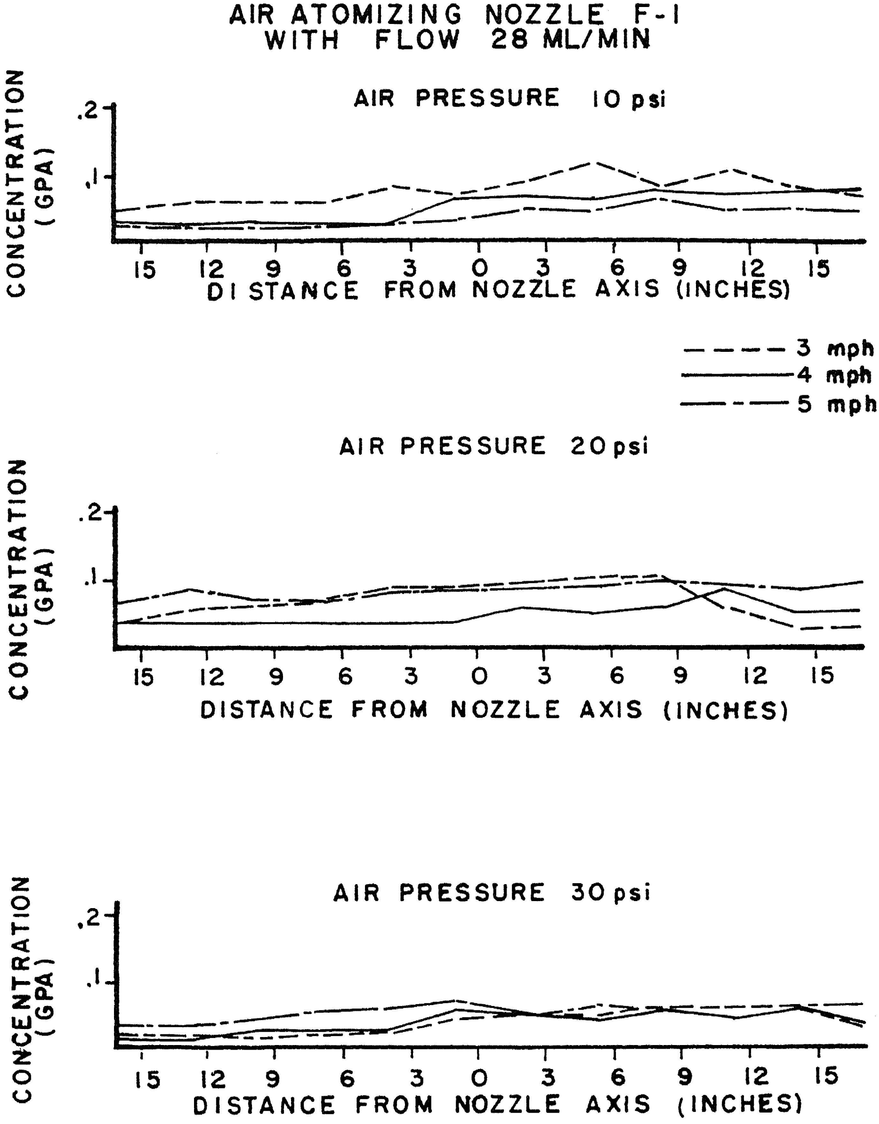

Fig. 12—Spray patterns from air atomizing nozzle with atomizing pressure at 10, 20, and 30 psi.

The analysis of variance showed no significant difference in mean concentration with the air nozzle regardless of flow rate, pressure, or speed. This error in mean concentration is due to the large percent of spray loss and fluctuations in flow rates from the nozzle. Thus, even though the air nozzle gives the most uniform pattern, additional research to reduce the flow rate error is required before it can be recommended as a low volume nozzle. Results of the spray distribution data for each nozzle are summarized in Table 2, and the data for each pressure and speed for the nozzles are listed in Appendix A.

TABLE 2--RESULTS OF SPRAY DISTRIBUTION DATA

Nozzle	Pressure (psi)	Percent Spray Loss	Individual C.U.	End Compensated C.U.
730039	25	24.2	62.3	68.4
Fan Spray	30	23.9	67.4	76.0
	40	17.4	76.2	92.4
730023	25	23.9	63.5	69.9
Fan Spray	30	15.7	69.2	80.0
	40	17.6	75.3	86.2
650017	25	43.9	51.6	57.1
Fan Spray	30	54.5	49.1	53.8
	40	19.9	71.5	82.4
TX-1	25	50.3	70.9	78.6
Cone Spray	30	34.2	70.8	80.9
	40	35.1	70.6	81.7
F-1, 28 ml/min	10	83.4	89.9	91.5
Air Atomizing	20	80.2	91.6	90.6
	30	86.1	89.6	92.6
F-1, 66 ml/min	10	70.8	80.2	93.1
Air Atomizing	20	73.5	87.2	90.7
	30	89.1	85.3	93.1

Results of Spread Factor Data

To be able to relate spot size on collection cards to the actual size of the droplet that produced the spot, the amount of spread was determined. The spread factor is the ratio of spot size to the droplet size.

Spread factor data were collected for two types of material: Scotchprint paper and Lusterkote cards. Droplets of various sizes ranging from 1,000 microns to 93 microns were produced. Table 3 summarizes the spread factors obtained for the two materials.

A linear regression equation was computed from the spread factor data for both types of materials. Appropriate "T" tests were applied to the correlation coefficient to determine if the slope of the regression equation was significantly

TABLE 3--SPREAD FACTOR

Replication Number	Lusterkote Cards* Size in Oil (Microns)	Lusterkote Cards* Size on Card (Microns)	Lusterkote Cards* Spread Factor	Scotchprint Paper* Size in Oil (Microns)	Scotchprint Paper* Size on Paper (Microns)	Scotchprint Paper* Spread Factor
1	1,000	2,407	2.40	800	1,000	1.25
2	833	2,133	2.60	700	867	1.24
3	833	2,000	2.40	667	867	1.30
4	767	2,066	2.70	600	733	1.22
5	733	1,900	2.60	600	767	1.24
6	667	1,667	2.50	567	667	1.17
7	667	1,567	2.40	533	733	1.33
8	580	1,313	2.26	533	600	1.12
9	567	1,333	2.40	533	667	1.25
10	553	1,240	2.24	500	667	1.33
11	540	1,300	2.41	500	600	1.20
12	534	1,333	2.50	467	583	1.25
13	513	1,186	2.31	400	533	1.33
14	490	1,196	2.44	400	483	1.20
15	467	1,100	2.35	333	400	1.20
16	467	1,233	2.64	333	400	1.20
17	467	1,100	2.36	167	200	1.20
18	467	1,067	2.30	300	400	1.33
19	450	1,153	2.56	133	160	1.20
20	434	1,000	2.30	93	120	1.30
21	227	534	2.35			
22	200	433	2.10			
23	173	400	2.30			
24	133	333	2.50			
25	120	267	2.20			
26	147	333	2.27			

*Fifteen drops measured for each replication and mean calculated. Various sized needles and frequency used to make various sized droplets.

different from zero. From the tests it was determined that the spread factor was constant for the Scotchprint paper but increased with an increase in droplet size for the Lusterkote cards.

A constant spread factor of 1.2365 was used for all droplet sizes collected on Scotchprint paper. The photographic negatives of the paper were enlarged exactly 2½ times; thus the spots scanned by the FSPA were 3.0914 times larger than the actual droplet size.

For Lusterkote cards the correlation coefficient was significantly different from zero; therefore, the value of spread factor depends on droplet size. To convert FSPA size classes to actual droplet sizes, the two spread factor equations were solved simultaneously.

1. Spread factor = 2.27278 + 0.000182 x droplet size.
2. Spread factor = spot size/droplet size; therefore,

$$\frac{\text{Spot size}}{\text{Droplet}} = 2.2728 + 0.000182 \times \text{droplet size or}$$

$$0.000182\ (\text{drop size})^2 + 2.27278\ (\text{drop size}) - \text{spot size} = 0.$$

Table 4 shows the actual droplet sizes for each size class analyzed on the FSPA for the two types of material used.

TABLE 4--DROPLET SIZE FOR SCOTCHPRINT PAPER AND LUSTERKOTE CARDS

Spot size scanned by FSPA (microns)	Droplet size Scotchprint paper (microns)	Droplet size Lusterkote cards (microns)
20	6.469	8.793
40	12.939	17.574
60	19.408	26.343
80	25.878	35.099
100	32.348	43.843
140	45.287	61.297
180	58.226	78.701
220	71.165	96.058
260	84.104	113.367
300	97.043	130.630
340	109.982	147.845
380	122.922	165.015
420	135.861	182.139
460	148.800	199.216
500	161.739	216.249
540	174.678	233.238
580	187.617	250.181
640	207.026	275.514
700	226.434	300.749
760	245.843	325.887
840	271.722	359.256
1,000	323.478	425.492
1,500	485.217	628.366
2,000	646.956	825.421

Results from Particle Size Determination

The degree of spray atomization was determined for the low volume nozzles by measuring the number of droplets, percent volume, and corresponding cumulative percent spray volume for 24 size classes of droplets. Test results are summarized in Appendix B. Operating pressure, speed, and flow rate are shown along with the mmd and the percent area covered.

An analysis of variance was computed for the mass median diameter and percent area covered. There was no significant difference in percent area covered for any combination of nozzle, pressure, or speed. Table 5 below summarizes the data for each nozzle.

TABLE 5--MASS MEDIAN DIAMETER AND PERCENT AREA COVERED FOR EACH NOZZLE AND PRESSURE

Nozzle	Pressure (psi)	% Area Covered	MMD (μ)	Nozzle	Pressure (psi)	% Area Covered	MMD (μ)
730039	25	2.12	339.3	TX-1	25	1.57	332.1
Fan	30	3.49	324.4	Cone	30	1.41	291.1
	40	3.96	274.3		40	2.03	230.7
730023	25	1.64	299.0	F-1	10	1.14	227.1
Fan	30	2.53	271.5	Air	20	0.44	241.1
	40	1.97	202.1	28 ml/min	30	0.26	193.9
650017	25	1.48	254.8	F-1	10	3.01	279.0
Fan	30	1.84	239.0	Air	20	1.58	240.1
	40	2.10	190.4	66/ml/min	30	0.76	333.1

The data show that the percent area covered ranged from 0.26 percent to 3.96 percent. This coverage is very low, and it is surmised that weed control is achieved because there is a radius of influence much greater than the droplet diameter. This zone of influence or halo of toxicity is not precisely known but varies with the type of material used as well as with the purpose of the spray. The volatility and solubility of the spray material are believed to be two major factors affecting the zone of influence. Some materials are believed to move in their gaseous phase to give weed control.

The atomization for the nozzles was significantly greater at the highest pressure as shown in Figure 13. The corresponding percent area covered showed a general increase with greater atomization, but it was not significant at the 5 percent level.

It is a popular belief that cone nozzles produce a finer spray than fan nozzles, but this was not true for the cone nozzle tested. Flow rates for cone nozzle TX-1 were comparable to those for fan nozzle 650017, and the mass median diameter of 246 microns for the cone nozzle was not significantly different from that of the fan nozzle of 227 microns. Actually, there was an unexpected similarity in the atomization of all the nozzles tested.

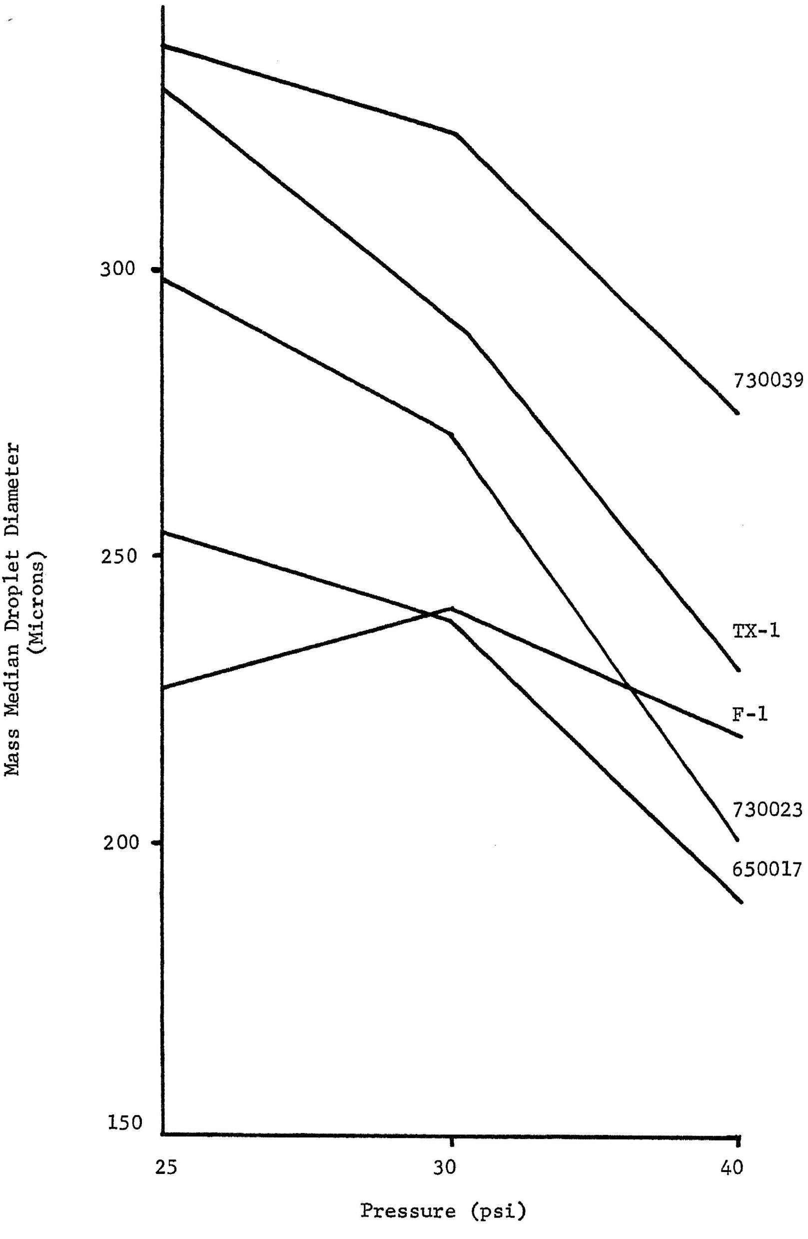

Fig. 13—Effect of nozzle pressure on droplet size.

The importance of atomization is shown by comparing droplet size with the number of drops and percent volume. The ideal atomization consists of droplets with nearly uniform droplet diameters. The optimum droplet size range is not known, but the objective is to provide adequate coverage without excessive drift or loss of ability of the spray to impact on the sprayed surface. For fan nozzle 730023, 932 droplets with diameters less than 129 microns contained 23 percent of the total spray volume. The same nozzle produced 18 droplets larger than 300 microns in diameter containing 36 percent of total volume.

Cone nozzle TX-1 provides a more ideal atomization. Five hundred and thirty-seven droplets with diameters less than 300 microns contained 13 percent of the spray, while 32 droplets greater than 300 microns contained 36 percent of the spray volume. The air nozzle with atomizing pressure at 30 psi contained 20 percent of the volume in 277 droplets less than 140 microns, with only one droplet larger than 300 microns containing 5 percent of total volume. Seventy-nine percent of the spray volume was contained in 72 droplets with diameters ranging from 122 to 288 microns.

The droplet size was plotted against cumulative percent volume for all tests. Figure 14 compares the fan, cone, and air nozzle at the highest pressure operated. The deposits from the fan and cone nozzles have a maximum droplet size (based on 99 percent cumulative volume) of approximately 500 microns. The air nozzle has a maximum diameter of about 300 microns. The data showing the number of droplets, percent volume of droplets, and cumulative percent volume for each of the twenty-four size classes of droplets are included in Appendix B for all the nozzle and pressure combinations.

The results of the droplet size data were not graphically compared with other research data because the flow rates were approximately ten times smaller than those found in other published data (17, 32). However, the results agree with Tate's (32) findings that there was unexpected similarity in atomization quality between flat and cone spray nozzles operated at similar conditions. The degree of atomization is believed to be relatively independent of the nozzle type as there was no significant difference in droplet size across the spray swath, percent area covered, or mass median diameter for comparable flow rates.

In summary, the spray deposit patterns and degree of liquid atomization from nozzles with flow rates ranging from 28 ml/min to 144 ml/min were evaluated. The results indicate that the spray patterns from the fan spray and cone spray nozzles are more uniform when operating at 40 psi than at 25 or 30 psi. Pressure does not significantly affect the deposit patterns of the air nozzle. Speeds of 3, 4, and 5 mph do not significantly affect the spray patterns of any of the nozzles tested.

The droplet size distribution did not vary significantly across the spray swath or with a change in speed for any of the nozzles tested. There was no significant difference in percent area covered for any combination of nozzle, pressure, or

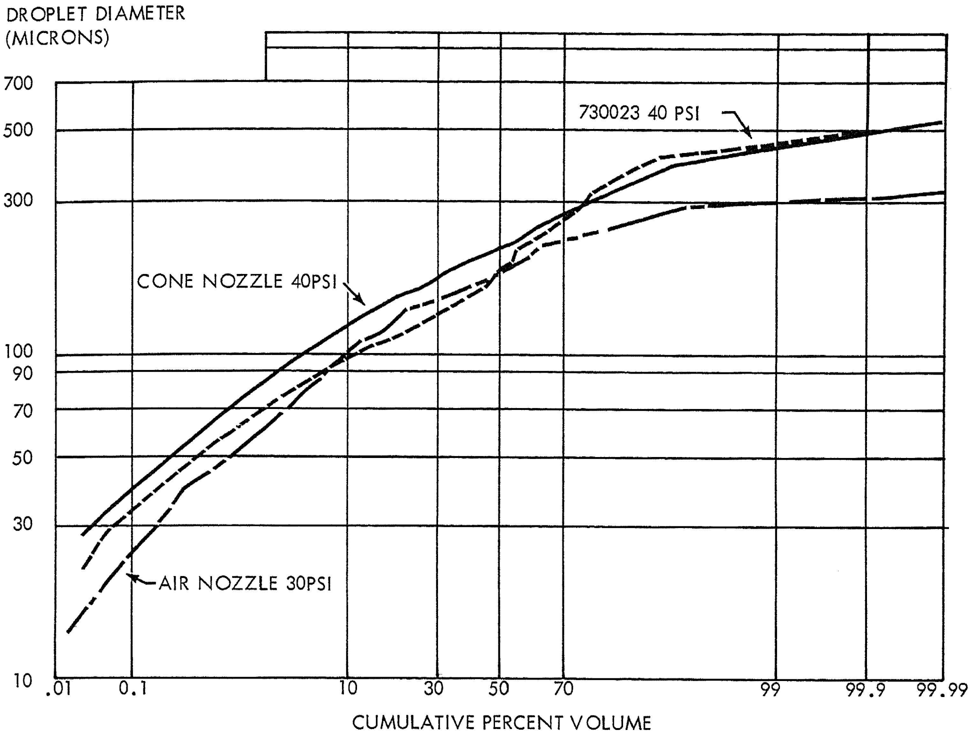

Fig. 14—Droplet size distribution curves for low volume spray nozzles.

speed. The mass median diameter decreased with an increase in pressure with the atomization for all the nozzles tested being very similar.

Since the spray distribution pattern data showed over 80 percent spray loss for the air nozzle, we cannot say that the collected portion of spray is a random sample of what the nozzle produces. The data more closely represent what is deposited on the sprayed surface when operating the nozzle at a 19-inch height. Therefore, the conclusions from this study should be considered valid only for the evaluation of the atomized liquid collected on the sprayed surface rather than the atomization at the nozzle tip.

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APPENDIX A

TABLE 1--RESULTS OF FLUORESCENT DATA FOR FAN SPRAY NOZZLE TIP 730039

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Per cent spray loss	S_{max}* ($\bar{X}\sqrt{N}$)	S** between plates	C.U.	S_{max} ($\bar{X}\sqrt{N}$)	S between plates	C.U.
25	3	2.537	1.948	23.2	4.482	1.653	63.11	5.511	1.692	69.29
	4	1.903	1.463	23.1	3.363	1.311	61.02	4.139	1.372	66.84
	5	1.522	1.123	26.2	2.585	0.955	63.06	3.175	0.979	69.16
30	3	2.929	2.210	24.6	5.035	1.653	67.17	6.251	1.539	75.38
	4	2.197	1.658	24.5	3.763	1.205	67.99	4.690	1.089	76.77
	5	1.758	1.357	22.8	3.063	0.999	67.37	3.838	0.923	75.94
40	3	3.505	2.661	24.1	5.307	1.155	78.25	7.525	0.330	95.61
	4	2.629	2.362	10.1	4.766	1.123	76.43	6.682	0.557	91.66
	5	2.134	1.748	18.1	3.642	0.942	74.15	4.943	0.492	90.04

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

TABLE 2--RESULTS OF FLUORESCENT DATA FOR FAN SPRAY NOZZLE TIP 730023

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Per Cent spray loss	S_{max}* ($\bar{X}\sqrt{N}$)	S** between plates	C.U.	S_{max} ($\bar{X}\sqrt{N}$)	S between plates	C.U.
25	3	1.726	1.174	32.0	2.707	1.073	60.37	3.321	1.135	65.84
	4	1.275	0.983	22.9	2.242	0.760	66.10	2.781	0.743	73.30
	5	1.020	0.849	16.8	1.945	0.698	64.10	2.400	0.704	70.66
30	3	1.857	1.514	18.4	3.307	0.958	71.02	4.284	0.727	83.04
	4	1.412	1.153	18.3	2.540	0.854	66.37	3.262	0.788	75.85
	5	1.130	1.010	10.6	2.244	0.667	70.29	2.856	0.534	81.30
40	3	2.302	2.016	12.4	3.952	0.854	78.38	5.701	0.524	90.81
	4	1.726	1.499	13.1	3.094	0.833	73.08	4.241	0.692	83.68
	5	1.381	1.003	27.4	2.090	0.534	74.45	2.837	0.445	84.33

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

TABLE 3--RESULTS OF FLUORESCENT DATA FOR FAN SPRAY NOZZLE TIP 650017

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Per cent spray loss	S_{max}* / $(\bar{X}\sqrt{N})$	S** between plates	C.U.	S_{max} / $(\bar{X}\sqrt{N})$	S between plates	C.U.
25	3	1.360	0.654	51.9	1.492	0.649	56.49	1.850	0.706	61.83
	4	1.020	0.538	47.3	1.214	0.665	45.17	1.522	0.761	49.98
	5	0.816	0.551	32.5	1.233	0.575	53.39	1.558	0.630	59.55
30	3	1.622	1.079	33.4	2.477	0.990	60.04	3.053	1.048	65.69
	4	1.216	0.576	52.6	1.296	0.589	54.57	1.629	0.647	60.28
	5	0.973	0.218	77.6	0.498	0.334	32.87	0.617	0.397	35.69
40	3	1.857	1.513	18.5	3.338	0.904	72.92	4.279	0.677	84.17
	4	1.393	1.125	19.2	2.418	0.613	74.67	3.182	0.402	87.36
	5	1.114	0.868	22.1	1.921	0.633	67.04	2.455	0.595	75.76

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

TABLE 4--RESULTS OF FLUORESCENT DATA FOR CONE SPRAY NOZZLE TIP TX-1

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Percent spray loss	S_{max}* $(\bar{X}\sqrt{N})$	S** between plates	C.U.	S_{max} $(\bar{X}\sqrt{N})$	S between plates	C.U.
25	3	1.229	0.681	44.6	1.525	0.522	65.74	1.925	0.511	73.44
	4	0.922	0.228	75.3	0.511	0.133	74.03	0.645	0.158	75.51
	5	0.738	0.508	31.1	1.046	0.282	73.02	1.437	0.188	86.92
30	3	1.360	0.811	40.4	1.781	0.482	72.95	2.294	0.356	84.48
	4	1.020	0.679	33.5	1.475	0.421	71.46	1.919	0.315	83.58
	5	0.816	0.580	28.9	1.322	0.423	68.05	1.642	0.414	74.77
40	3	1.569	1.043	33.5	2.275	0.674	70.39	2.950	0.534	81.90
	4	1.177	0.794	32.5	1.716	0.469	72.69	2.247	0.326	85.51
	5	0.942	0.569	39.5	1.269	0.395	68.87	1.610	0.357	77.85

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

TABLE 5--RESULTS OF FLUORESCENT DATA FOR AIR ATOMIZING NOZZLE TIP F-1, 28 ML/MIN

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Percent spray loss	S_{max}* $(\bar{X}\sqrt{N})$	S** between plates	C.U.	S_{max} $(\bar{X}\sqrt{N})$	S between plates	C.U.
10	3	0.732	0.134	81.7	0.262	0.021	91.82	0.378	0.037	90.26
	4	0.549	0.092	83.3	0.183	0.022	88.06	0.260	0.016	93.91
	5	0.439	0.065	85.2	0.129	0.013	89.83	0.184	0.017	90.59
20	3	0.732	0.103	85.9	0.208	0.025	87.76	0.291	0.021	92.75
	4	0.549	0.078	85.9	0.148	0.014	90.45	0.219	0.025	88.60
	5	0.439	0.137	68.9	0.272	0.010	96.35	0.387	0.036	90.62
30	3	0.732	0.067	90.8	0.133	0.017	86.91	0.190	0.016	91.72
	4	0.549	0.063	88.4	0.126	0.015	88.21	0.180	0.009	94.99
	5	0.439	0.092	79.1	0.182	0.011	93.91	0.260	0.023	91.33

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

TABLE 6--RESULTS OF FLUORESCENT DATA FOR AIR ATOMIZING NOZZLE TIP F-1, 66 ML/MIN

		End Compensation			Individual Nozzle			End Compensation		
Pressure (psi)	Speed (mph)	Nozzle flow rate (gpa)	Mean concentration (gpa)	Percent spray loss	S_{max}* ($\bar{X}\sqrt{N}$)	S** between plates	C.U.	S_{max} ($\bar{X}\sqrt{N}$)	S between plates	C.U.
10	3	1.726	0.748	56.7	1.527	0.262	82.85	2.117	0.077	96.37
	4	1.216	0.245	79.9	0.510	0.111	78.19	0.692	0.064	90.78
	5	1.067	0.258	75.8	0.503	0.103	79.57	0.731	0.057	92.15
20	3	1.674	0.321	80.8	0.655	0.097	85.19	0.907	0.082	90.98
	4	1.255	0.409	64.4	0.831	0.129	84.51	1.156	0.143	87.68
	5	1.004	0.248	75.3	0.495	0.040	91.94	0.702	0.046	93.46
30	3	1.674	0.100	94.0	0.199	0.016	92.08	0.282	0.015	94.62
	4	1.255	0.172	86.3	0.344	0.049	85.65	0.485	0.023	95.27
	5	1.036	0.133	87.1	0.271	0.059	78.33	0.377	0.040	89.49

*Maximum standard deviation which is the average concentration on the plates times square root of the number of plates (N = 12).

**Standard deviation between the twelve sampling plates.

APPENDIX B

TABLE 1--RESULTS OF PARTICLE SIZE DATA

Nozzle	Pressure (psi)	Speed (mph)	Flow Rate (gpa)	Per Cent Area Covered	Mass Median Diameter
Fan Spray No. 730039	25	3	2.537	2.67	326.6
		4	1.903	2.39	346.1
		5	1.522	1.32	348.5
	30	3	2.929	3.84	318.6
		4	2.197	4.24	335.0
		5	1.758	2.38	310.2
	40	3	3.505	5.79	302.6
		4	2.629	3.43	258.0
		5	2.134	2.67	244.0
Fan Spray No. 730023	25	3	1.726	1.83	306.2
		4	1.275	2.21	284.9
		5	1.020	.90	365.7
	30	3	1.857	3.31	284.4
		4	1.412	2.25	307.2
		5	1.130	2.02	198.5
	40	3	2.302	2.12	228.9
		4	1.726	2.09	228.1
		5	1.381	1.71	166.7
Fan Spray No. 650017	25	3	1.360	1.78	237.7
		4	1.020	1.25	242.9
		5	0.816	1.41	286.1
	30	3	1.622	1.97	238.1
		4	1.216	1.85	234.1
		5	0.973	1.70	242.5
	40	3	1.857	2.82	193.1
		4	1.393	1.65	159.7
		5	1.114	1.83	219.4

TABLE 1 (continued)

Nozzle	Pressure (psi)	Speed (mph)	Flow Rate (gpa)	Per Cent Area Covered	Mass Median Diameter
Cone Spray TX-1	25	3	1.229	2.54	344.9
		4	0.922	1.04	344.8
		5	0.738	1.15	259.7
	30	3	1.360	1.63	259.7
		4	1.020	1.50	307.9
		5	0.816	1.09	344.0
	40	3	1.569	2.57	205.6
		4	1.177	2.16	284.2
		5	0.942	1.38	197.3
Air Atomizing Setup F-1 28 ml/min.	10	3	0.732	.98	221.9
		4	0.549	1.34	215.7
		5	0.439	1.11	245.5
	20	3	0.732	.56	235.0
		4	0.549	.47	241.2
		5	0.439	.29	275.5
	30	3	0.732	.14	147.8
		4	0.549	.34	235.4
		5	0.439	.29	155.0
Air Atomizing Setup F-1 66 ml/min.	10	3	1.726	4.19	254.2
		4	1.216	2.89	302.1
		5	1.067	1.94	288.6
	20	3	1.674	1.76	218.7
		4	1.255	1.91	254.8
		5	1.004	1.08	241.4
	30	3	1.674	1.04	335.9
		4	1.255	.62	267.1
		5	1.036	.64	409.0

TABLE 2--SPRAY DROPLET SIZE DISTRIBUTION DATA FOR FLAT SPRAY NOZZLE 730039

Droplet Size Range (micron)	25 psi			30 psi			40 psi		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 6.5	18	0	0	17	0	0	30	0	0
6.5 - 12.9	8	0	0	12	0	0	18	0	0
12.9 - 19.4	16	0	0	11	0	0	38	0	0
19.4 - 25.9	7	0	0	20	0	0	42	0.01	0.01
25.9 - 32.3	14	0.01	0.01	15	0	0	34	0.01	0.02
32.3 - 45.3	19	0.02	0.03	40	0.03	0.03	92	0.07	0.09
45.3 - 58.2	27	0.07	0.10	58	0.09	0.12	111	0.19	0.28
58.2 - 71.2	22	0.11	0.22	53	0.16	0.29	139	0.47	0.75
71.2 - 84.1	16	0.14	0.36	72	0.38	0.67	120	0.71	1.46
84.1 - 97.0	25	0.36	0.72	47	0.39	1.06	130	1.22	2.68
97.0 - 110.0	35	0.75	1.47	70	0.88	1.94	147	2.06	4.74
110.0 - 122.9	21	0.64	2.10	74	1.32	3.26	225	4.49	9.23
122.9 - 135.9	14	0.58	2.69	74	1.81	5.07	123	3.37	12.60
135.9 - 148.8	36	2.00	4.68	71	2.32	7.39	94	3.42	16.02
148.8 - 161.7	20	1.44	6.12	45	1.90	9.30	84	3.97	20.00
161.7 - 174.7	16	1.47	7.59	37	1.99	11.29	58	3.49	23.48
174.7 - 187.6	8	0.91	8.50	26	1.75	13.04	42	3.15	26.64
187.6 - 207.0	16	2.25	10.75	32	2.64	15.68	48	4.43	31.07
207.0 - 226.4	14	2.74	13.50	28	3.22	18.90	25	3.21	34.29
226.4 - 245.8	12	3.04	16.54	34	5.06	23.96	27	4.49	38.78
245.8 - 271.7	18	6.00	22.54	16	3.14	27.10	30	6.57	45.35
271.7 - 323.5	13	6.59	29.13	39	11.62	38.73	35	11.65	57.00
323.5 - 485.2	42	53.42	82.55	60	44.86	83.59	46	38.42	95.42
485.2 - 647.0	5	17.45	100.00	8	16.41	100.00	2	4.58	100.00
Mass Median Diameter		339.30			324.42			274.28	
Percent Area Covered		2.12			3.49			3.96	

TABLE 3--SPRAY DROPLET SIZE DISTRIBUTION DATA FOR FLAT SPRAY NOZZLE 730023

Droplet Size Range (micron)	25 psi			30 psi			40 psi		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 6.5	11	0	0	11	0	0	17	0	0
6.5 - 12.9	8	0	0	10	0	0	20	0	0
12.9 - 19.4	10	0	0	16	0	0	22	0	0
19.4 - 25.9	3	0	0	23	0	0	40	0.01	0.01
25.9 - 32.3	15	0.01	0.01	37	0.02	0.02	27	0.02	0.03
32.3 - 45.3	26	0.04	0.05	98	0.11	0.13	67	0.13	0.16
45.3 - 58.2	31	0.11	0.16	90	0.24	0.38	92	0.41	0.57
58.2 - 71.2	37	0.26	0.42	86	0.46	0.84	98	0.86	1.44
71.2 - 84.1	40	0.49	0.91	116	1.06	1.90	109	1.65	3.08
84.1 - 97.0	50	0.97	1.88	87	1.26	3.16	106	2.54	5.63
97.0 - 110.0	19	0.55	2.43	59	1.28	4.44	97	3.48	9.10
110.0 - 122.9	29	1.20	3.63	77	2.38	6.82	135	6.89	15.99
122.9 - 135.9	23	1.30	4.93	55	2.33	9.14	98	6.86	22.85
135.9 - 148.8	19	1.43	6.36	46	2.59	11.73	74	6.89	29.75
148.8 - 161.7	22	2.15	8.51	61	4.46	16.20	45	5.44	35.19
161.7 - 174.7	24	2.98	11.50	47	4.37	20.57	34	5.23	40.42
174.7 - 187.6	27	4.19	15.69	36	4.18	24.75	18	3.46	43.87
187.6 - 207.0	19	3.63	19.32	42	6.00	30.75	22	5.20	49.07
207.0 - 226.4	23	6.11	25.43	33	6.57	37.32	8	2.63	51.70
226.4 - 245.8	15	5.16	30.59	19	4.89	42.21	14	5.96	57.66
245.8 - 271.7	16	7.24	37.83	17	5.76	47.97	12	6.72	64.38
271.7 - 323.5	17	11.70	49.53	12	6.18	54.15	8	6.81	71.19
323.5 - 485.2	21	36.26	85.79	30	38.76	92.91	8	17.09	88.28
485.2 - 647.0	3	14.21	100.00	2	7.09	100.00	2	11.72	100.00
Mass Median Diameter		298.98			271.55			202.08	
Percent Area Covered		1.64			2.53			1.97	

TABLE 4--SPRAY DROPLET SIZE DISTRIBUTION DATA FROM FLAT SPRAY NOZZLE 650017

Droplet Size Range (micron)	25 psi			30 psi			40 psi		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 6.5	7	0	0	6	0	0	20	0	0
6.5 - 12.9	10	0	0	10	0	0	16	0	0
12.9 - 19.4	7	0	0	6	0	0	17	0	0
19.4 - 25.9	14	0.01	0.01	19	0.01	0.01	22	0.01	0.01
25.9 - 32.3	12	0.01	0.02	11	0.01	0.02	34	0.02	0.03
32.3 - 45.3	17	0.03	0.05	32	0.05	0.07	57	0.09	0.12
45.3 - 58.2	29	0.14	0.19	53	0.22	0.29	52	0.20	0.32
58.2 - 71.2	41	0.39	0.58	67	0.53	0.82	70	0.52	0.84
71.2 - 84.1	34	0.56	1.14	58	0.80	1.61	86	1.11	1.96
84.1 - 97.0	46	1.20	2.34	62	1.35	2.96	96	1.97	3.94
97.0 - 110.0	37	1.44	3.78	58	1.89	4.85	77	2.36	6.30
110.0 - 122.9	36	2.00	5.78	64	2.96	7.82	89	3.89	10.19
122.9 - 135.9	36	2.74	8.52	54	3.43	11.25	78	4.68	14.87
135.9 - 148.8	25	2.53	11.05	42	3.55	14.80	83	6.63	21.50
148.8 - 161.7	20	2.63	13.68	38	4.17	18.97	73	7.57	29.06
161.7 - 174.7	30	5.01	18.69	42	5.86	24.83	45	5.93	34.99
174.7 - 187.6	34	7.10	25.79	40	6.97	31.81	50	8.23	43.22
187.6 - 207.0	17	4.36	30.16	31	6.65	38.45	47	9.51	52.74
207.0 - 226.4	18	6.43	36.59	21	6.27	44.72	17	4.79	57.53
226.4 - 245.8	16	7.40	43.99	11	4.25	48.97	13	4.74	62.27
245.8 - 271.7	12	7.30	51.29	16	8.13	57.10	10	4.80	67.07
271.7 - 323.5	15	13.88	65.18	16	12.37	69.47	5	3.65	70.71
323.5 - 485.2	15	34.82	100.00	13	25.21	94.68	16	29.29	100.00
485.2 - 647.0	0	0	100.00	1	5.32	100.00	0	0	100.00
Mass Median Diameter		254.78			239.00			190.37	
Percent Area Covered		1.48			1.84			2.10	

TABLE 5--SPRAY DROPLET SIZE DISTRIBUTION DATA FROM CONE SPRAY NOZZLE TX-1

Droplet Size Range (micron)	25 psi			30 psi			40 psi		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 6.5	11	0	0	9	0	0	12	0	0
6.5 - 12.9	11	0	0	10	0	0	13	0	0
12.9 - 19.4	7	0	0	9	0	0	15	0	0
19.4 - 25.9	2	0	0	15	0	0	17	0	0
25.9 - 32.3	7	0	0	25	0.02	0.02	22	0.01	0.01
32.3 - 45.3	10	0.01	0.01	30	0.05	0.07	34	0.05	0.06
45.3 - 58.2	13	0.04	0.05	33	0.13	0.20	61	0.21	0.27
58.2 - 71.2	21	0.13	0.18	34	0.26	0.46	59	0.40	0.67
71.2 - 84.1	12	0.13	0.31	28	0.36	0.82	61	0.71	1.38
84.1 - 97.0	11	0.19	0.50	24	0.50	1.32	59	1.08	2.46
97.0 - 110.0	25	0.66	1.17	27	0.83	2.15	66	1.81	4.27
110.0 - 122.9	26	0.97	2.15	29	1.27	3.43	59	2.30	6.58
122.9 - 135.9	17	0.87	3.02	29	1.75	5.17	59	3.16	9.74
135.9 - 148.8	18	1.23	4.25	24	1.93	7.10	47	3.35	13.09
148.8 - 161.7	15	1.33	5.58	26	2.71	9.81	45	4.16	17.25
161.7 - 174.7	28	3.15	8.73	25	3.31	13.12	55	6.47	23.72
174.7 - 187.6	10	1.41	10.14	18	2.98	16.10	29	4.26	27.99
187.6 - 207.0	16	2.77	12.90	24	4.88	20.98	44	7.95	35.94
207.0 - 226.4	16	3.85	16.76	18	5.10	26.08	40	10.07	46.01
226.4 - 245.8	12	3.74	20.50	13	4.76	30.85	17	5.53	51.54
245.8 - 271.7	14	5.74	26.24	22	10.61	41.46	19	8.14	59.68
271.7 - 323.5	13	8.10	34.34	14	10.27	51.73	18	11.73	71.41
323.5 - 485.2	31	48.49	82.83	18	33.12	84.85	12	19.61	91.03
485.2 - 647.0	4	17.17	100.00	3	15.15	100.00	2	8.97	100.00
Mass Median Diameter		332.07			291.06			230.73	
Percent Area Covered		1.57			1.41			2.03	

TABLE 6--SPRAY DROPLET SIZE DISTRIBUTION DATA FOR AIR ATOMIZING NOZZLE F-1 WITH FLOW RATE OF 28 ML/MIN

Droplet Size Range (micron)	10 psi atomizing pressure			20 psi atomizing pressure			30 psi atomizing pressure		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 8.8	39	0	0	20	0	0	25	0	0
8.8 - 17.6	73	0	0	38	0.01	0.01	30	0.01	0.01
17.6 - 26.3	82	0.03	0.03	36	0.03	0.04	28	0.06	0.07
26.3 - 35.1	99	0.09	0.13	55	0.12	0.16	31	0.17	0.24
35.1 - 43.8	101	0.20	0.33	28	0.13	0.28	20	0.23	0.47
43.8 - 61.3	189	0.88	1.21	58	0.63	0.92	45	1.24	1.72
61.3 - 78.7	157	1.73	2.94	48	1.24	2.15	40	2.61	4.33
78.7 - 96.1	93	1.99	4.93	38	1.90	4.06	20	2.54	6.87
96.1 - 113.4	101	3.73	8.66	35	3.02	7.08	13	2.84	9.71
113.4 - 130.6	59	3.44	12.10	22	3.00	10.08	16	5.53	15.24
130.6 - 147.8	54	4.68	16.78	22	4.46	14.54	9	4.62	19.86
147.8 - 165.0	52	6.39	23.17	28	8.05	22.59	16	11.66	31.52
165.0 - 182.1	49	8.23	31.40	16	6.29	28.88	8	7.96	39.48
182.1 - 199.2	22	4.90	36.30	7	3.65	32.52	7	9.24	48.72
199.2 - 216.2	23	6.62	42.93	9	6.06	38.58	4	6.82	55.54
216.2 - 233.2	17	6.20	49.12	5	4.26	42.85	2	4.32	59.86
233.2 - 250.2	14	6.35	55.47	7	7.43	50.28	4	10.75	70.61
250.2 - 275.5	12	6.67	62.14	4	5.20	55.47	3	9.88	80.49
275.5 - 300.7	6	4.61	66.75	7	12.58	68.05	3	13.66	94.15
300.7 - 325.9	11	10.87	77.62	1	2.31	70.36	1	5.85	100.00
325.9 - 359.3	1	1.29	78.91	1	3.02	73.38	0	0	100.00
359.3 - 425.5	6	11.64	90.56	1	4.54	77.93	0	0	100.00
425.5 - 628.4	2	9.44	100.00	2	22.07	100.00	0	0	100.00
628.4 - 825.4	0	0	100.00	0	0	100.00	0	0	100.00
Mass Median Diameter		227.09			241.09			193.89	
Percent Area Covered		1.14			0.44			0.26	

TABLE 7--SPRAY DROPLET SIZE DISTRIBUTION DATA FOR AIR ATOMIZING NOZZLE F-1 WITH FLOW RATE OF 66 ML/MIN

Droplet Size Range (micron)	10 psi atomizing pressure			20 psi atomizing pressure			30 psi atomizing pressure		
	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume	Number of Drops	Percent Volume	Cumulative Volume
0.0 - 8.8	19	0	0	106	0	0	57	0	0
8.8 - 17.6	19	0	0	176	0.01	0.01	74	0.01	0.01
17.6 - 26.3	13	0	0	201	0.04	0.05	87	0.03	0.04
26.3 - 35.1	26	0.01	0.01	221	0.13	0.18	94	0.08	0.12
35.1 - 43.8	14	0.01	0.02	225	0.27	0.45	99	0.19	0.31
43.8 - 61.3	56	0.06	0.08	440	1.26	1.71	134	0.60	0.90
61.3 - 78.7	25	0.06	0.14	271	1.83	3.54	108	1.13	2.03
78.7 - 96.1	50	0.25	0.39	219	2.88	6.41	95	1.94	3.97
96.1 - 113.4	58	0.50	0.88	151	3.41	9.82	56	1.97	5.94
113.4 - 130.6	59	0.80	1.68	126	4.50	14.33	45	2.50	8.44
130.6 - 147.8	64	1.29	2.97	87	4.62	18.95	31	2.56	11.00
147.8 - 165.0	82	2.34	5.31	69	5.20	24.15	25	2.93	13.93
165.0 - 182.1	101	3.94	9.25	54	5.56	29.71	23	3.68	17.61
182.1 - 199.2	109	5.63	14.88	49	6.69	36.39	16	3.39	21.00
199.2 - 216.2	112	7.48	22.37	28	4.94	41.33	19	5.21	26.22
216.2 - 233.2	101	8.55	30.91	23	5.14	46.47	14	4.86	31.08
233.2 - 250.2	55	5.79	36.70	14	3.89	50.36	10	4.32	35.40
250.2 - 275.5	63	8.12	44.83	12	4.09	54.45	11	5.82	41.23
275.5 - 300.7	42	7.49	52.32	16	7.53	61.98	6	4.39	45.62
300.7 - 325.9	31	7.11	59.43	3	1.82	63.79	2	1.88	47.50
325.9 - 359.3	19	5.70	65.12	6	4.75	68.54	3	3.69	51.19
359.3 - 425.5	37	16.67	81.79	7	8.33	76.87	3	5.55	56.74
425.5 - 628.4	14	15.33	97.13	8	23.13	100.00	7	31.47	88.21
628.4 - 825.4	1	2.87	100.00	0	0	100.00	1	11.79	100.00
Mass Median Diameter		279.01			240.15			333.14	
Percent Area Covered		3.01			1.58			0.76	