1978

Influence of electrostatic potentials on rotating discs for liquid spraying

Adhemar Brandini
Iowa State University

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INFLUENCE OF ELECTRICAL POTENTIALS ON ROTATING DISCS FOR LIQUID SPRAYING.

IOWA STATE UNIVERSITY, PH.D., 1979
Influence of electrostatic potentials on rotating discs for liquid spraying

by

Adhemar Brandini

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of DOCTOR OF PHILOSOPHY

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A. Requirement for Spray Formulation</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>B. Biological Effectiveness</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>C. Recent Proposed Improvement</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>II. LITERATURE REVIEW</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>A. Rotating Disc Atomizers</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>B. Electrostatics: Its Influence on Dispersion and Deposition of Particulates</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>III. OBJECTIVES</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>IV. DATA ACQUISITION</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>A. Equipment</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>B. Materials and Methods</td>
<td></td>
<td>59</td>
</tr>
<tr>
<td>C. Test Procedure</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>D. Experimental Design</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>V. RESULTS</td>
<td></td>
<td>72</td>
</tr>
<tr>
<td>A. Spray Charging Characteristics</td>
<td></td>
<td>72</td>
</tr>
<tr>
<td>B. Droplet Size Characteristics</td>
<td></td>
<td>72</td>
</tr>
<tr>
<td>VI. DISCUSSION</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>A. Spray Charging Process</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>B. Droplet Size Distribution</td>
<td></td>
<td>91</td>
</tr>
<tr>
<td>VII. SUMMARY</td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>VIII. CONCLUSIONS</td>
<td></td>
<td>121</td>
</tr>
<tr>
<td>Appendix</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>IX.</td>
<td>BIBLIOGRAPHY</td>
<td>124</td>
</tr>
<tr>
<td>X.</td>
<td>ACKNOWLEDGEMENTS</td>
<td>133</td>
</tr>
<tr>
<td>XI.</td>
<td>APPENDIX A. SPRAY CHARGING CHARACTERISTICS</td>
<td>135</td>
</tr>
<tr>
<td>XII.</td>
<td>APPENDIX B. RAW DATA FROM PARTICLE SIZE ANALYZER</td>
<td>139</td>
</tr>
<tr>
<td>XIII.</td>
<td>APPENDIX C. COMPUTER PROGRAM</td>
<td>185</td>
</tr>
<tr>
<td>XIV.</td>
<td>APPENDIX D. DROPLET SIZE DISTRIBUTION BY STATION (EXAMPLES SELECTED AT RANDOM)</td>
<td>213</td>
</tr>
<tr>
<td>XV.</td>
<td>APPENDIX E. SUM DISTRIBUTION BY RUN</td>
<td>219</td>
</tr>
<tr>
<td>XVI.</td>
<td>APPENDIX F. RADIAL DISTRIBUTION BY RUN</td>
<td>265</td>
</tr>
<tr>
<td>XVII.</td>
<td>APPENDIX G. SPRAY DISPERSION</td>
<td>311</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

The increasing demand for food, fiber and fuel has pushed most of the technically advanced societies toward the improvement of agricultural production. Displacement of mules and oxen by tractors and sickles by combines has been continuous during the last four decades. Economics has dictated heavy fertilization of soils accompanied by application of large amounts of insecticides and other pesticides for crop protection as well as herbicides for weed control.

Although the use of pesticides in agriculture started shortly after the discovery by Millardette in the 1880's that Bordeaux Mixture was effective in the control of downy mildew of grapes (Horsfall, 1956), accelerated development started after World War II. The phenoxy-alliphatic herbicides and the chlorinated hydrocarbon insecticides were introduced for general domestic and agricultural use. These chemicals were inexpensive, effective in very small doses, and had low mammalian toxicity. The success and widespread adoption of these chemicals started an endless search for other chemicals to achieve specific objectives and to substitute for some former chemicals either banned or under restrictions for specific purposes.

The development of the pesticide applicators has not
been as successful as the development of the chemicals. In general, for liquid application using ground equipment pressure nozzles are the only application device used, although a large variation in their design and construction exists. The low-volume and ultra-low-volume (ULV) nozzles prevail for farm use, with a marked increase for the second type in recent years. The amount of liquid to be applied for insect control varies considerably but is generally 100 to 200 liters/ha (10 to 20 gallons/acre) for the low volume applicators, compared with 2 to 3 liters/ha for the ULV.

The older high-volume applicators, like the costal ones, would use up to 2,400 l/ha for a single application, depending upon the crop and pest being treated.

A. Requirement for Spray Formulation

Many of the actual pesticide chemicals are liquids, or can be emulsified or put into solution with commercial solvents. Dust formulations have lost popularity due to high transport costs, large amounts of very fine particles which drift easily even at low speed winds, and poor weather resistance, i.e., they are easily removed by rainwashing (Green et al., 1977).

The liquid formulation has satisfactorily been applied
to plants, animals, and the soil as a spray, using ground equipment with conventional pressure nozzles as well as by aerial applicators. However, due to the increasing prices of particular chemicals and restriction imposed by environmental agencies on the use of most of the agricultural pesticides and herbicides, a real challenge is presented to farmers, engineers and scientists, concerned with pesticide applicators. Although the spray produced by a conventional pressure nozzle can be controlled reasonably well the droplet size range is still very wide. This characteristic, although not undesirable per se, has the disadvantage that only a portion of the sprayed material is deposited upon the intended target, while the remainder is deposited some place where it is wasted or its presence is considered undesirable.

1. Drift

Drift is the process of transporting material away from the intended target by aerodynamic forces applied on the spray droplets, causing the pesticide chemical to settle on sites distinct from where it was intended to be deposited. Drift of a herbicide onto a crop which is sensitive to the chemical may kill the crop. Drift of other chemicals onto crops for which there exist no legal tolerances for residues may result in unmarketable crops. In either case,
drift may cause large economic losses and cause individuals responsible for the drift to be sued for compensation for the damage. Yates and Akesson (1973) showed that even under good weather conditions, spraying upwind of a field of alfalfa hay closer than 600 feet with 1.6 lb/A of DDT would result in deposits of chemical on the hay which exceeded legal limits for marketing. Skoog et al. (1976) studying aircraft applications of pesticides at ULV reported drift of particles as large as 100 microns above the height of the aircraft and 110 meter distant.

Controlling spray drop size for precision spray applications appears to be the most logical approach for reducing, if not eliminating, the aerial transport or drift of small particles. Chemical loss can take place: (a) by direct aerial loss at the time of application; (b) by direct application losses to soil under sprayed crop; (c) by transfer from crop plants to soil and thence to ground water (not large with low water solubility); (d) by losses to water run-off or to wind transport of plant materials and soil particles; and (e) by losses of pesticides carried on raw produce processed in central canning, freezing, or fresh-food plants, in which case the pesticide chemicals are peeled or removed with outer leaves or are washed off and become contaminants of sewage systems,
from which they flow into the waterways and finally into the oceans (Akesson et al., 1970).

2. **Deposition efficiency**

Deposition efficiency is a measure of the amount of applied chemicals deposited on target plants. The smaller the value, the higher is the proportion of chemicals lost. Bowen et al. (1952a) reported the amount of chemicals deposited on target plants by conventional spraying and dusting equipment. Although very large variation was found the average deposition was between 5 and 15 percent of the total amount used.

Reeves et al. (1967) reported that only 5.1 percent of the total liquid sprayed was deposited on simulated cotton plants.

Johnstone and Johnstone (1977) reported results of field trials carried out in Swaziland during the 1974-1975 cotton season for aerial applications using very low-volume and ultra-low volume sprays, at rates of 10-15 l/ha of water as carrier and spray droplet size of 120-150 μ volume mean diameter (vmd), and at rates of 5 l/ha, waterless, using droplet size of 80-120 μ vmd. For the very-low-volume formulation, application at 10:24 hours and 13.0 m height with slightly unfavorable meteorological conditions, the volume recovery was only 2.2 percent, but for application at
05:30 hours and 4.5 m height and with favorable conditions the volume recovery was 10 percent.

Green et al. (1977) indicated the growth of the world pesticide industry in the period 1945-1975 with the following figures in thousands of tonnes: 1945 (100), 1955 (400), 1965 (1000), 1970 (1500), and 1975 (1800). In the United States the total pesticide (herbicides, fungicides and insecticides) production was 643,000 tonnes during 1974, which represented a wholesale value of $1,732 million.

The economics of herbicide usage are easier to observe than those of insecticides or fungicides, since herbicides are essentially used as a substitute for mechanical or hand weeding and can be assessed on this basis. In 1975 only 50 man-hours were required to grow and harvest a hectare of cotton using chemical weeding and defoliation and mechanical picking, compared with 200 man-hours in 1933 for manual hoeing and picking. Similarly, according to Green et al. (1977), in 1975 only 22 man-hours were necessary to grow and harvest one hectare of corn producing 5000 kg of grain, against 135 man-hours in 1945.

From the cost-benefit view, Green et al. (1977) reported that experiments with potatoes over a period of ten years indicated $6.71 average return for each $1.00 spent on pesticides, and a similar study on apples showed that $5.17
was returned for each $1.00 spent for pesticides.

3. Atmospheric pollution

One of the major criticisms made by environmentalists concerned with pesticide uses is that they often affect organisms other than those intended, due more to inadequate methods of application than to the characteristics of the chemicals. Generally, due to local atmospheric conditions some of the spray becomes airborne for sufficient length of time to cause an environmental hazard, in addition to the loss of the chemical.

Yates and Akesson (1973) reported levels up to 2 $\mu$g/m$^3$ of air, for 2-hour averaged levels in the air during seasonal application of 2,4-D herbicide. Pesticide chemicals become hazardous contaminants based on their tendency to vaporize, their degree of solubility in water or other solvents, and their resistance to the normal degradation process. The actual application equipment produces spray with a widely variable droplet size distribution. These distributions generally fit a log-normal model and in some cases result in a droplet size spectrum showing more than a 20-fold range of droplet diameters from the same application equipment. Some of this equipment produces a large percent of very fine particles highly susceptible to drift and airborne transport under unfavorable meteorological
conditions. Design parameters and concepts of chemical sprayers are important variables affecting atmospheric pollution caused by agricultural chemicals, and these can be controlled and modified, contrary to the weather parameters which are outside of the control of the operator.

To improve control of deposition from spray application equipment a large number of forces known to affect small particles has been investigated by a number of researchers. Aerodynamic forces, thermal gradient forces, and electrostatic forces have been applied to spray droplets to cause changes in their trajectories. Menzies (1975) tested a hydraulic fan nozzle showing drastic elimination of droplets smaller than 100 μ from the main spray. Brazee and Bucelle (1959) reported a summary of several investigations related to electrostatic precipitation of dusts. Smith et al. (1970) developed a narrow spectrum droplet generator by using a spinning disc. Tests showed that about 60-70 percent of the atomized liquid was recovered at the collector. The large reduction in drift was due to the very homogeneous size of the droplets released.
B. Biological Effectiveness

A number of investigators have reported evidence that a pesticide may change its biological effect as a function of the droplet size produced. Investigations with modern insecticides conducted by Yeomans et al. (1949) showed that the most effective diameter for DDT spray for control of mosquitoes was approximately 12 microns.

Hedden (1961) tested the effectiveness of disease control by different chemicals on several vegetable crops using sprays having mass median droplet sizes from 100 microns to 500 microns. Poor control of droplet size probably explains the conclusion that little if any variation in disease control resulted from use of different droplet sizes. Ennis and Williamson (1963) concluded that the herbicidal activity of several chemicals increased as the droplet size decreased, when the volume of liquid used was low. Skoog et al. (1965) using ultra low volume spray methods for rangeland grasshopper control speculated that the reduction in droplet size might be responsible for increased effectiveness. Frick (1970) investigating the optimum droplet size for effective control of apple powdery mildew by Dinocap found that 175 micron droplet diameter produced the best disease control.

Wilson et al. (1963) conducted experimental work over
a 3-year period on spray droplet size as related to disease and insect control on row crop. The results showed that droplets within the range 50 to 100 microns in diameter are the most effective in controlling small insects, while for large insects (bugs) the optimum diameter size falls into the range 150 to 200 microns.

Smith et al. (1975) recommended a droplet size of 100-140 microns for bollweevil control but noted that this is too small for drift control; as a compromise a droplet size of 140-200 microns should be acceptable for both drift and boll-weevil control using ground equipment.

C. Recent Proposed Improvement

The increasing interest in producing more uniform spray droplets as an attempt to reduce chemical waste and environmental pollution has brought several new concepts into practice. Some of these although working in laboratory under very specific conditions are impractical for field utilization.

New pressure nozzles for drift reduction have resulted in a significant reduction of the number of droplets smaller than 100 micron diameter (Brandenburg, 1974; Tate, 1977. Roth and Porterfield (1966) proposed the use of Rayleigh break-up from small jets of liquid produced by low pressure
discharge through hypodermic tubing to obtain homogeneous droplets of about 580 microns, at a rate up to 3,000 droplets per second per tube. The natural satellites formed averaged 180 microns in diameter and were removed from the main stream during laboratory trials by an electrostatic potential. During field tests complete separation of the satellites was not possible.

Roth and Porterfield (1970) controlled the atomization of a jet stream of a nonconductive liquid discharging through an orifice in a thin piezoelectric crystal. An A-C electric signal impressed across the crystal faces produced a cyclic dimensional change in the orifice, thus creating the jet stream disturbance.

Bouse et al. (1974) exploited the Rayleigh jet stream instability by introducing pressure pulses in a liquid-filled chamber which induced a cyclic disturbance on the jet stream. Frequencies up to 30 kHz were used and droplet size from 120 to 720 microns in diameter were produced depending upon the orifice diameter of the capillary tube used. Only occasional formation of satellites was reported, but these usually coalesced with the major drops a short distance from the orifices.

Law and Bowen (1966) proposed charging the liquid spray by electrostatic induction to reduce drift and to improve
chemical deposition on the plant targets. Field tests on cotton showed significant increase in spray coverage of the bottom side of the cotton leaves. An average increase of 3.8 times occurred in leaf bottom coverage due to charging the spray.

Burt et al. (1966) applied the spinning disc atomizer principle to agricultural work. They introduced an inwardly radial air flow over the periphery of the disc to remove fine satellite drops prior to their having left the disc. The diameter of the remaining droplets had a coefficient of variation of approximately 0.1, thus showing good uniformity.

Mathews (1978) has proposed an improvement of spinning discs or cups to produce droplets of almost uniform size, which is called "controlled droplet application" (CDA). This is based on the capability of rotating discs to provide large variations of the mean diameter of the spray by varying the disc speed. It has been suggested that further improvement in the efficiency of spraying may be possible by electrostatically charging these more uniformly sized droplets.
II. LITERATURE REVIEW

The search for a liquid spray having the desirable qualities of homogeneous size droplets small enough to increase biological effectiveness and to reduce the amount of solvent or liquid carrier, but large enough to avoid drift and excessive evaporation during settling, and therefore reducing if not eliminating the environmental pollution, has been a challenge for researchers working on pesticide application. It has been shown in the introduction that such an ideal pesticide application device is not yet commercially available. However, a slow but constant progress has been made by researchers in this area, applying basic physical principles in their work.

Two fundamental aspects toward such improvement are discussed in the literature: the utilization and characteristics of rotating disc atomizers for liquid spraying and the use of electrostatic potentials as a mean to disperse liquids.

A. Rotating Disc Atomizers

Atomization results from an energy source acting on liquid bulk. The minimum energy for atomization is that required to create the new surface. The theoretical energy required to create a liquid droplet neglecting the energy of the liquid bulk can approximately be expressed as:
\[ E_s = \pi d^2 \sigma \] (1)

where

- \( d \) = diameter of the drop formed
- \( \sigma \) = surface tension
- \( E_s \) = energy required to create a new surface

Rotating disc atomizers belong to the class of centrifugal energy atomizers. They can be subdivided into vaned disc atomizers and smooth disc atomizers. The latter comprise the cup, bowl, and plate shaped discs.

In rotating disc atomizers, the liquid is fed onto the disk surface, near the center, and then is centrifugally accelerated to high velocity before being discharged into the surrounding atmosphere. The liquid extends over the rotating surface as a thin film. The degree of atomization depends upon peripheral speed, feed rate, liquid properties and atomizer design. Maximum kinetic energy is imparted to the liquid when the liquid acquires the disc peripheral speed prior to discharge. If a flat smooth disc is rotating at high speed and liquid is fed on its top surface, severe slippage occurs between the liquid and the disc surface. When slippage occurs the tangential velocity of the liquid prior to discharge is smaller than that of the disc and atomization will be unsatisfactory. To prevent slippage at moderate and high feed rates and/or
at high speed of the rotating disc, radial vanes are used. The liquid is confined to the vane surface, and at the external disc edge the maximum possible liquid release velocity is attained. This maximum velocity is the vector sum of the radial and tangential velocity of the liquid at the external edge of the vanes.

1. Smooth flat rotating disc atomizers

The disintegration of liquid into droplets from a rotating (flat) disc as presented by Masters (1972) is governed by:

1. The viscosity and surface tension of the liquid;
2. Inertia of the liquid (density);
3. Friction effects between the liquid droplets and surrounding air at the point of release from the disc;
4. Readjustment of shear stresses within the liquid droplet once the droplet becomes airborne.

At low peripheral speeds, the liquid viscosity and surface tension are the predominant factors. When the liquid feed rate is also very low the mechanism of atomization predominates, i.e., droplets are formed and released from the disc edge. Generally two or three prominent droplets are formed as the parent droplets, and then two satellites.

With increasing feed rates and disc speeds the direct
droplet formation mechanism changes to one of ligament break-up. The points where the direct droplet formation would start have more liquid, and ligaments begin to extend out of the disc edge until a point where disintegration starts. Parent droplets as well as satellite droplets are formed. The higher the liquid viscosity and surface tension the larger the parent droplets formed. Increase in liquid viscosity also increases the proportion of satellite droplets in the spray. Spherical droplets are formed regardless of the value of the liquid surface tension. Viscosity and surface tension are physical properties of the feed liquid. The inertial forces start predominating over the liquid properties when the ligaments join to form a liquid sheet extending beyond the disc edge. This mechanism of atomization is often referred to as the velocity spraying mechanism, according to Adler and Marshall (1951a,b). Liquids exhibiting high viscosity produces a more accentuated liquid sheet. The sheet disintegrates giving a spray of broad droplet size distribution. Increasing the disc speed while maintaining a constant feed rate causes the liquid sheet to retract towards the disc edge. If the feed rate is increased with disc speed, the velocity spraying mechanism (sheet formation) continues. When slippage of the feed liquid over the disc is minimized or eliminated, the velocity of the liquid
at the disc edge can be high enough to enable air frictional effects at the liquid-air interface to become the controlling atomization mechanism. The mode of disintegration of the retracting sheet causes great difficulty in the formation of a homogeneous spray. Use of liquids of high viscosity and surface tension reduces the broad size distribution, as does an increase of disc tangential speed while keeping a constant feed rate. To produce a narrow size distribution, high speeds are required at low feed rates. In general most of the laboratory work on rotating discs as a generator of homogeneous droplet sprays were conducted at very low feed rates and at very high speeds.

Hinze and Milborn (1950) studied the atomization of liquids produced by rotating cups. Disc diameters of 1.0 cm, 2.5 cm, and 10.0 cm were used and the liquids tested were fuel oils with a wide range in viscosity. They proposed two basic dimensionless groups $S_I$ and $F_I$ to characterize the transition between the different atomization mechanisms as:

$$S_I = \omega D (\rho D/\sigma)^{1/2}$$  \hspace{1cm} (2)

$$F_I = Q/D (\rho/\sigma D)^{1/2} (\mu/(\sigma \rho D)^{1/2})^{1/6}$$  \hspace{1cm} (3)

where the symbols are as defined in Equation 4. The transition between ligament formation and sheet formation
is given experimentally by the following equation as shown in Figure 1.

\[
\frac{Q}{D} \left( \sqrt{\frac{\rho}{\sigma D}} \right) \left( \omega D \sqrt{\frac{\rho D}{\sigma}} \right)^{0.60} \left( \frac{\mu}{\sqrt{\rho \sigma D}} \right)^{0.167} = 133
\]

\text{(4)}

where

\begin{align*}
Q & : \text{liquid feed rate, } L^3 T^{-1} \\
D & : \text{rotating cup diameter, } L \\
\rho & : \text{liquid density, } ML^{-3} \\
\sigma & : \text{liquid surface tension, } MT^{-2} \\
\mu & : \text{liquid dynamic viscosity, } ML^{-1} T^{-1} \\
\omega & : \text{rotating atomizer angular velocity, } T^{-1}
\end{align*}

Figure 1. Atomization mechanism for rotating cup: transition of atomization mechanisms (after Hinze and Milborn, 1950)
Frazer et al. (1957) verified severe slippage on smooth flat discs as occurring whenever

\[ \frac{M}{\pi \mu d} \geq 1440 \quad (5) \]

where

- \( M \): mass feed rate, in lb/hr;
- \( \mu \): liquid viscosity, in cp;
- \( d \): disc diameter, in ft.

The same authors derived, for an ideal disc without slippage, equations to express flow conditions where liquid break-up at the disc edge is due to ligament or sheet disintegration. The two dimensionless parameters employed are similar to those used by Hinze and Milborn (1950), as shown in Equations 2 and 3, but were tested for different feed rates and rotating discs.

Boize and Dombrowski (1976) investigated the atomization characteristics of a spinning disc as an ultra-low-volume applicator. The atomizer was a special design combining feature of a rotating disc and cup and measured 88 millimeters in external diameter. It was tested with a number of oils ranging in viscosity from 0.0073 to 0.0603 kg/m.s. It was found that the mechanism of droplet formation depended upon the operating conditions. At low feed rates and low speeds, drops were produced directly
from the periphery of the disc and good monodisperse spray was obtained. At high feed rates and high speeds wide droplet size spectra were produced. Comparison of the experimental data showing the transition between the single drop formation and the ligament formation with the theoretical equation proposed by Hinze and Milborn (1950),

\[
\frac{Q}{d^5} \left[ \frac{d}{\nu} \right]^{0.5} \left[ \frac{d}{\nu} \right]^{0.5} \left[ \frac{d}{\nu} \right]^{0.25} \left( \frac{\mu}{\rho d} \right)^{0.5} < 4.55 \times 10^{-3}
\]

(6)
did not match due to the difference in atomizer designs. The experimental values for feed rate were considerably larger than the theoretical ones for the low speeds, up to 6000 rpm, used in the experiments.

Droplet sizes produced by smooth flat discs have been studied by Walton and Prewett (1949), Adler and Marshall (1951), Friedman et al. (1952), Marshall (1954), Frazer et al. (1957) and Masters (1972). Masters (1972) summarized the findings as shown in Table 1.
Table 1. Droplet size prediction for smooth flat discs (after Masters, 1972)\(^a\)

<table>
<thead>
<tr>
<th>Atomization mechanism</th>
<th>Equation</th>
<th>Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct drop formation</td>
<td>(D_{max} = \frac{64 \times 10^4}{N} \sigma^{0.5} ) (^\text{(7)})</td>
<td>Bär (1935)</td>
</tr>
<tr>
<td>Ligament break-up</td>
<td>(D_{max} = \frac{52.2 \times 10^4}{N} \sigma^{0.5} ) (^\text{(8)})</td>
<td>Walton and Prewett (1949)</td>
</tr>
<tr>
<td></td>
<td>(D_{sv} = \frac{2.67 \times Q^{0.2}}{N \rho^{0.3}}) (^\text{(9)})</td>
<td>Oyama and Endou (1953)</td>
</tr>
<tr>
<td>Sheet disintegration</td>
<td>(D_{ave} = \frac{45.5 \times 10^4}{N} \sigma^{0.5} ) (^\text{(10)})</td>
<td>Frazer et al. (1957)</td>
</tr>
</tbody>
</table>

\(D_{ave}\) - average droplet diameter, in microns; 
\(D_{max}\) - maximum droplet diameter, in microns; 
\(D_{sv}\) - Sauter droplet diameter, in microns;
\(N\) - rotating disc speed, in rpm;
\(d\) - rotating disc diameter, in cm;
\(\sigma\) - liquid surface tension, in dynes/cm;
\(\rho\) - liquid density, in g/cm\(^2\);
\(v\) - liquid kinematic viscosity, in cm\(^2\)/s;
\(Q\) - liquid feed rate, in cm\(^3\)/s.

As reported by Friedman et al. (1952) and Masters (1972) these equations are of only limited interest for commercial spraying conditions. However, the equations indicate the relationships between droplet size operating variables, and physical properties.
2. **Vaned rotating disc atomizers**

The mechanisms of atomization applied to vaned rotating discs are very similar to those related to smooth flat rotating discs. The presence of vanes constrains the liquid to acquire a velocity upon release from the vane edges equal to or greater than the peripheral disc velocity. Although this mechanism does not lend itself to the formation of homogeneous spray, small droplet sizes can be produced. In the commercial range of conditions (high feed rates at high disc speeds) liquid disintegration starts right at the external vane edges by frictional effects between air and the liquid surface as the liquid emerges as a thin film from the vanes. According to photographic studies by Marshall (1954), and Herring and Marshall (1955), the extended distance from the external vane edges where the spray is formed depends upon the disc speed and the liquid feed rate. For high discharges and low speed, . . . the liquid discharged from each vane retained its streamshaped identity for some distance beyond the disc, where it then broke-up. The break-up occurred as the end of the stream spread out into a sheet which flapped like a flag. Heavy ligaments extended from this sheet and also trailed from the main stream between the sheeted end and the disc periphery. From the ligaments and from the sheet itself, irregular globs and drops of varied sizes were formed as shown in the high-speed movie frames (Herring and Marshall, 1955).
Masters (1972) observed that increasing the viscosity and surface tension of the liquid act to improve spray uniformity, but at the expense of smaller mean droplet size. Dombrowski and Lloyd (1974) confirmed these findings in using a rotary cup of 4.0-inch diameter rotating at 82 Hz and using water and three different oils more viscous than water, at feed rates from 20 to 100 ml/s.

Adler and Marshall (1951a,b), Friedman et al. (1952), Marshall (1954), Herring and Marshall (1955), Frazer et al. (1957), Masters and Mohtadi (1967), Masters (1972), and Dombrowski and Lloyd (1974), have presented relationships between the spray droplet size produced by vaned rotating disc atomizers and the liquid properties and atomizer design parameters. Most of this work was related to spray drying and covered a wide range of parameters. Results obtained by the different researchers are in close agreement.

A prediction equation in terms of dimensionless groups has been proposed by Friedman et al. (1952) as:

\[
\frac{D_{sv}}{r} = 0.4\left(\frac{Q}{\rho_1 N r^2}\right)^{0.6} \left(\frac{\mu}{Q}\right)^{0.2} \left(\frac{\rho_1 \sigma L}{Q^2}\right)^{0.1}
\]

(11)

The range of variables on which Equation 11 was based were: liquid viscosity, \( \mu \): 1 to 9,000 centipoises; liquid density, \( \rho_1 \): 62.4 to 88 lb/cu ft; surface tension, \( \sigma \): 74 to 100 dynes/cm; rotary atomizer radius, \( r \): 1 to 4 inches;
wetted periphery, $L$: 0.36 to 19.2 inches; disc speed, $N$: 860 to 18,000 rpm; liquid feed rate, $M$: 0.55 to 67.5 lb/min; and mass flow rate, $Q$: 1.5 to 90 (lb/min)/ft.

Frazer et al. (1957) proposed an alternate equation to predict the mean spray size, in terms of the Sauter diameter, produced by rotary atomizers (flat discs and bowls as well as vaned discs) as:

$$d_{sv} = 4.2 \times 10^4 \left( \frac{L}{N} \right)^{0.6} \left( \frac{M}{D_0} \right)^{0.5} \left( \frac{\eta}{\rho_L} \right)^{0.2} \left( \frac{\gamma}{L} \right)^{0.1}$$

(12)

This equation was proposed as valid for the following operating range: disc diameter, $D_0$: 0.17-0.67 ft; disc speed, $N$: 860-18,000 rpm; liquid feet rate, $M$: 33-4,050 lb/hr; liquid surface tension, $\gamma$: 74-100 dynes/cm; liquid density, $\rho$: 62.4-88 lb/ft$^3$; and liquid viscosity, $\eta$: 1-900 centipoise.

Rationalization of Equations 11 and 12 yields the same result within ten percent. For both equations the parameters used and respective units are:

- $d_{sv}$: droplet surface mean diameter, in microns;
- $D_{sv}$: droplet surface mean diameter, in ft;
- $N$: rotary atomizer speed, in rpm;
- $L$: wetted perimeter, in ft
  $$L = \pi D_0 \text{ for flat discs and bowls;}$$
  $$L = nb \text{ for vaned discs;}$$
- $D_0$: rotating atomizer diameter, in ft;
n: number of vanes;
b: height of a vane, in ft;
r: radius of the rotary atomizer, in ft;
M: liquid mass feed rate, in lb/hr;
Q: liquid mass feed rate per unit length of wetted perimeter, in (lb/min)/ft;
µ: liquid viscosity, in lb/ft.min;
ρ: liquid density, in lb/ft\(^3\);
σ: liquid surface tension, in lb/ft\(^2\);
η: liquid viscosity in centipoise;
γ: liquid surface tension, in dynes/cm.

Although no confidence intervals were calculated for the regression equations, Friedman et al. (1952) suggested that Equation 11 within the range of variables covered presents an accuracy that can be expected to be \(\pm 30\) percent or better, which he believed to suffice for almost all design purposes.

Friedman et al. (1952) compared data obtained by Adler and Marshall (1951b) and Hinze and Milborn (1950) using Equation 11. Although equal slopes can be assumed for them, Hinze and Milborne (1950) obtained poor agreement with Equation 11. The disagreement has been attributed to a number of causes, as: differences in drop-sampling procedures, differences in total number of drops counted, etc. In fact,
Friedman et al. (1952) did their weight-distribution sampling in a plane 10 inches below the atomizer while Herring and Marshall used the distance of 36 inches. Evaporation of droplets could be the major cause for the differences.

Herring and Marshall (1955) in analyzing the disc atomizer parameters and liquid feed rate, presented a generalized drop size distribution correlation, as given by Equation 13,

\[ y = x(ND_0)^{0.83}(nb)^{0.12}/Q^{0.24} \]  
(13)

where

- \( y \): median droplet diameter parameter
- \( x \): spray droplet size, in microns
- \( N \): disc speed, in rpm
- \( D_0 \): disc diameter, in inches
- \( n \): number of vanes
- \( b \): height of a vane, in inches
- \( Q \): liquid feed rate, in lb/min

Plotting results from Equation 13 on square-root-normal probability coordinates resulted in a straight line having constants:

- \( y_{\text{median}} = 92.5 \times 10^2 \)
- \( \sigma_y = 49.0 \times 10^2 \)

Extension of the correlation given by Equation 13 to higher disc speeds, lower feed rates and smaller discs was
indicated to be feasible by drop-size data from a 2-inch diameter disc rotating at speeds up to 32,500 rpm with feed rates of less than 1.0 lb/min. Slightly different parameters were obtained from the plotted data, but for any practical purpose the given Equation 13 can be used to predict within 25 percent or better the drop size distribution of sprays produced by straight-vaned discs.

Herring and Marshall (1955) analyzing former data for comparison with the proposed generalized correlation given by Equation 13 found that data supplied by Adler and Marshall (1951b) well-fitted the correlation; however droplet sizes from data by Friedman et al. (1952) were substantially smaller than predicted by Equation 13, while Adler and Marshall (1951b) obtained greater average drop size. These differences were reported as due to the different experimental techniques used.

It can be observed from the data collected by former workers on spray production that with flow rates comparable to those used in the drying industry, the spray formed cannot be considered monodisperse. In fact, as noted by Yates and Akesson (1973), at flow rates comparable to those used in commercial agricultural applications, these sprays are very similar in drop size distribution to those from commercial agricultural sprayers i.e., they are polydisperse. Despite this fact the rotary sprayers offer some attractive
features for use in agriculture: the units are capable of producing a very fine spray, in the range of 10 to 40 microns for the volume mean diameter, and generally are almost free of clogging problems.

Among the research carried out on rotary atomizers for agricultural purposes are those of Roth and Reins (1957), Burt et al. (1966), Smith et al. (1970), Bode et al. (1972), Walker and Walton (1972), Goering et al. (1972), Sudit et al. (1973) and Menzies and Fisher (1975).

Goering et al. (1972) developed a shielded spinning disc atomizer in an attempt to obtain more homogeneous spray droplets. Liquid was fed at the rate of 0.0042 gallon/min (0.26 ml/s) on a 7-inch diameter disc rotating at 3600 rpm. This device, produced spray with a mass median diameter of 234 microns and a coefficient of variation of 118 percent. At a flow rate of 0.0224 gallon/min (1.41 ml/s), the figures were 359 microns and 118 percent for the mass median diameter and coefficient of variation respectively. The feed rates used were very low, much lower than are used in conventional pressure nozzles for pesticide applications. These low feed rates may be responsible for the good homogeneity of the spray produced.

Sudit et al. (1973) improved a rotating drum type atomizer, providing the cylindrical rim on its periphery
with a row of holes of 1.0 mm diameter drilled toward the center of the disc and spaced at 3.14 mm intervals. Tests of a rotating atomizer 70 mm in diameter, and rotating at 6000 rpm, using transformer oil as the liquid, showed the three distinct atomization mechanisms for feed rates of 0.049 ml/s, 1.0 ml/s, and 3.7 ml/s, respectively. For the lowest feed rate, direct droplet formation occurred at the external periphery of the holes. Seventy percent of the volume consisted of nearly uniform sized droplets (150 µ), about 20 percent of the volume was in 60 to 100 micron droplets, and the remaining 10 percent was in larger droplets (180 µ).

The second mechanism of atomization was characterized by the formation of continuous liquid streams leaving each hole and breaking up into droplets of uniform size at a certain distance from the external rim. In this case 20 percent of the volume was represented by droplets from 20 to 60 micron diameter, 70 percent of the volume comprised droplets from 60 to 110 micron diameter and the remaining 10 percent represented droplets between 110 and 150 micron diameter.

When feed rate was increased to 3.7 ml/s the third atomization mechanism took place in which the drum discharges a continuous film that breaks down from the effects of random disturbances into droplets of various
sizes, forming a polydisperse spray similar to those produced in conventional atomization, containing droplets from 20 to about 400 microns in diameter.

This sequence is very similar to the findings of Dombrowski and Lloyd (1974) and Boize and Dombrowski (1976) in studying atomization of liquids by spinning cups.

B. Electrostatics: Its Influence on Dispersion and Deposition of Particulates

Brief historical reviews of electrostatics are given by Moore (1973) and Green (1973). Until the late 18th century, little was added to the scientific knowledge of electrostatics since the remote era of about 500 B.C. when the Greek philosopher Thales experimented with amber and observed strange phenomena when rubbing it on silk or wool fabrics. By 1600, William Gilbert published his famous "De Magnete" based on many ingenious experiments he had conducted, including experiments involving electrostatics. He called the observed attractions "electric" after the Greek word of amber. In the 1660's Otto von Guericke, of Magdeburg, Germany, made the first known electrostatic generator, using an amber ball on a shaft turned with a crank. The ball became electrically charged after being rubbed.

Francis Hauksbee, an Englishman, in 1709 improved the
von Guericke electrostatic generator by replacing the amber with a glass ball. Later leather was used to substitute for the hands for rubbing the rotating glass balls.

In 1733 the Frenchman Abbe Nollet and Charles Francis de Cisternay Dufay discovered the polarity of electrical charges, one exhibited by rubbed glass and the other type exhibited by rubbed amber. Later in 1747, Benjamin Franklin designated these electrical charges as positive (+) and negative (−), respectively, when provided by rubbed glass or amber. He was also the formulator of the basic theory of capacitors, and he made some using Leyden jars.

Alessandro Volta introduced in 1775 the first induction type of electrostatic generator and in 1800 he introduced the chemical electric battery. Charles A. Coulomb in 1785 formulated the basic equations related to electric forces among electrically charged particles. In 1787 Abraham Bennet invented the gold-leaf electroscope. After Oerstead, Ampère and Ohm, Michael Faraday, in 1832, introduced the idea of lines of force in the electric field around charged bodies.

The basic rotating inductive electrostatic generator invented by C. F. Valey in 1860 was improved by James Wimshurst, an English engineer, in 1868. Two or more glass discs rotating in opposite directions were able to generate higher voltage than the earlier models. The major use of the Wimshurst generator was to operate the early x-ray tubes.
In 1929 R. J. Van de Graaff invented the belt-driven electrostatic generator which supplanted the Wimshurst ones. However, the limited output in terms of current (and power) persisted. This continued until the transformer-rectifier combination was introduced, overcoming these previous restraints to industrial application of electrostatic principles.

Among the numerous modern applications of electrostatics, the electrostatic precipitators was the major break coming around 1906, by F. G. Cottrell. Its first application in the United States was to control pollution originating from smelters and cement mills.

Other applications such as electrostatic separation of minerals and other mixtures, and paint spraying came later.

Unfortunately, electrostatics has also been responsible for new nuisances and hazards. Some of these are associated with new technologies such as high speed printing machines acquiring a build-up of electric charges at high levels. More serious problems arise with a build-up of electric charges creating electrostatic potentials and fields so high that spark formation results in often disastrous explosions, in grain elevators, supertanker ships, cotton-fiber processing plants and the like.

Most of these nuisances and hazards involving liquids have been studied under the topic of static charging by
spray electrification. This subject has been studied since 1892 by a number of workers and reported in detail by Loeb (1958). For small liquid discharge through a nozzle, a very small current can be expected flowing from the liquid to the reservoir walls. Moore (1973) showed that when water is sprayed by means of an air blast, a total current of about $10^{-6}$ A can be expected for a flow rate of 1 kilogram per second, which would correspond to an average specific charge of $10^{-6}$ C/kg of sprayed water. In general this type of electrification is undesirable and must be eliminated or minimized.

A second phenomenon involving a liquid subjected to an electrostatic field is the electrostatic dispersion. An electric field normal to the surface of a conducting liquid induces surface charges, which set up electrostatic forces opposed to the binding surface-tension forces of the liquid. A sufficiently high electric field can disrupt a liquid surface so that charged droplets can be produced.

Although the two phenomena, spray electrification and electrostatic spray generation, are related, they have fundamentally opposite effects; the spray electrification is generated by a mechanical disruption of the liquid, while in electrostatic spray generation the mechanical disruption of the liquid is caused by an accumulation of electric
charges on the liquid surface due to the presence of an intense electrostatic field.

The first recorded investigations on electrostatic dispersion according to Drozin (1955), and Bailey (1974), were by George M. Bose in 1745. He found that high potentials applied to certain liquids contained in a glass tube ending in a fine capillary, changed from threads to a highly dispersed aerosol consisting of droplets of relatively uniform size. After Bose, Zeleny (1917) related the required potentials to the forces required to overcome the surface tension and rupture the liquid surface.

Vonnegut and Neubauer (1952), investigating the electrical dispersion of liquids, found that under certain conditions a very fine monodisperse aerosol was obtained. The observed Higher Order Tyndall Spectra indicated the high degree of monodispersity with a droplet size of about 1 micron diameter.

Based on his experiments, Drozin (1955) observed that the dielectric constant of a liquid is a good indicator of its dispersibility. Therefore, some liquids like xylol, toluene, benzene, and carbon tetrachloride did not disperse even at high potentials up to 30 kV, when using a capillary tube of about 60 micron diameter, set up at 100 millimeters from the ground potential. Chloroform and ether showed fine
threads of liquid after high potentials were applied, while water, glycerin, methyl alcohol, acetone, ethyl nitrate, and acetic acid showed fine dispersibility when high potentials were used. Drozin further concluded that substances with specific conductivity lower than $10^{-11} \text{S.m}^{-1}$ and higher than $10^{-3} \text{S.m}^{-1}$ cannot be dispersed. He also observed that fine dispersion was possible only if positive potentials were applied, as was reported by Vonnegut and Neubauer (1952), although Pierce (1959) reported the opposite situation, with stable regimes only possible under negative potentials. Taylor (1964) showed theoretically and experimentally that liquid cones protruding from capillary tubes subjected to high potentials were stable for apex angles from $180^\circ$ to $98.6^\circ$, when disintegration occurred.

Carson and Hendricks (1965) used a metal capillary tip of 100 micron diameter set at 5 mm from the accelerating electrode. Glycerin and octoil were used at flow rates between $10^{-10}$ kg/s and $10^{-9}$ kg/s. At potentials below the critical value of 3.5 kV the spray was observed to be along or near the axis of the capillary, and it originated from liquid adhering to the capillary. At voltages above the critical value spray occurred in one or more jets, which originated along the periphery of the capillary tube and no liquid adhered to the capillary. The authors observed a
large number of droplets emitted during each spraying pulse, as Zeleny found previously, but contradicting the findings of Pierce (1959).

Burayev and Vereshchagin (1972) derived two analytical expressions to describe the electrostatic atomization of liquids through a capillary tube subjected to high potential. From the liquid characteristics and the geometry of the capillary tube one predicts whether a fine spray will occur, starting from the end of the droplet by local surface instability caused by corona current, or, if the droplet surface instability occurs close to the capillary, resulting in separation of large droplets without noticeable corona discharge. The experimental results agreed well with the predictions.

For the group with corona discharge occurring first, the authors listed water and ethylene glycol exhibiting corona-discharge field intensities of 7.75 kV/cm and 7.26 kV/cm, respectively. For the second group, presenting surface instability first, toluene and isopropyl alcohol were listed. The values of critical field intensity at the tip of droplets for these liquids were, respectively, 6.83 kV/cm and 5.56 kV/cm. They concluded that atomization of liquids having a high surface tension is presented by a corona discharge ensuing at the surface.

Bailey (1976) studied a twin blade, sharp-edged sprayer
unit under a vacuum of about $10^{-6}$ torr. Glycerol doped with sodium iodide was fed at flow rates between $3 \times 10^{-9}$ kg/s and $6 \times 10^{-8}$ kg/s, and potentials up to 16 kV. Droplets in the range of 9 to 25 microns were observed, and spray currents were found from $12 \times 10^{-6}$ A/kV to $24 \times 10^{-6}$ A/kV.

It can be observed from basic investigations on electrostatic dispersion of liquids that no homogeneous or normalized treatment has been used by the various scientists. This results in very meager and unreliable information for testing the physical and mathematical models that have been proposed. It can be observed that electrostatic dispersion has been successfully accomplished at expenses of very high potentials and extremely low flow rates. The spray droplet size has also been very small: from 1 to 25 microns when corona discharge prevails, for the reported experiments. The liquid physical properties largely influence its electrostatic dispersion. The geometry and arrangement of the electrostatic spray generator and the value of the applied potential are crucial parameters for a successful application. This accounts in part for the absence of more precise information on electrostatics for certain purposes.

Despite such difficulties some industrial application were developed and have improved very markedly since the pioneering days.
Allen (1963) conducted a comparative study for the painting industry. He studied the Ransburg No. 2 electrostatic coating process using a disc rotating at 900 rpm, with negative potentials on the disc up to 90,000 V. Paint flow rates were fixed at 250 ml/min, and the disc was set up at 30 inches from the panels. It was observed that in general the Ransburg No. 2 method is quite comparable both in particle size and particle size distribution, with the hand spray. However, the hand spray produced smaller particles. Also, increasing the applied potentials from 30 kV to 90 kV increased fineness of atomization. Viscosity caused no significant effect on the sprayed panels for zero potential applied, but with a 90 kV potential atomization became more irregular with a decrease in paint viscosity. Recommended paint resistivity is from $5 \times 10^4 \ \Omega \cdot \text{cm}$ to $1.0 \times 10^6 \ \Omega \cdot \text{cm}$.

Jones and Thong (1971) used electrostatic potentials to disperse a kerosene jet into a spray of monodisperse droplets. They found that monodisperse spray can be achieved within a small range of applied potentials, within which droplet size is almost independent of potential and is a function of the liquid (kerosene) flow rate. A chemical additive was used to increase the electric conductivity of the pure kerosene from $3 \times 10^{-12} \ \text{S/m}$ to $1 \times 10^{-6} \ \text{S/m}$. Flow rates up to 0.4 ml/min were used and two different capillary
tubes were employed. The capillary tip was set up at 3.0 cm from a brass disc. Monodisperse sprays were formed at 3.65 kV with the smaller capillary and at 4.15 kV with the larger one. For the flow rate of 0.4 ml/min, a droplet size of 110 microns was achieved. Derivation of a theoretical equation for the potential applied to the capillary as a function of the distance from the ground plate was established as

\[ \phi_0 = \frac{E_0}{\sqrt{r}} \ln \left( \frac{4Z_0}{r_c} \right) \]  

where

- \( E_0 \): electric field intensity at the capillary tip, V/m; \( E_0 = 4.17 \times 10^6 \) V/m, for \( r_c = 0.226 \) mm, \( Z_0 = 3.0 \) cm, and \( \phi_1 = 4.15 \) kV
- \( r_c \): external radius of the capillary, m
- \( Z_0 \): distance from the tip of capillary to the ground, m
- \( \phi_0 \): applied potential to the capillary, V

Specific applications of electrostatics in agriculture have been reported mainly for dust charging and deposition and for spray charging; both involved with pesticide applications.

MacLeod and Smith (1943) were probably the first investigators in the United States to carry out investigations to determine the magnitudes and polarities of dust charges as affected by pesticide materials, and the deposition
efficiency on an electrically charged plate simulating a plant leaf. Several other investigators followed, here and abroad. Brazee and Buchele (1959) presented an outline of research and literature on electrostatic precipitation of pesticidal dusts.

Gallwitz (1960) conducted laboratory and field investigations on the effects of electrostatic charging of sprays for plant protection. Water and oil based liquids were tested. Particles negatively charged presented a higher degree of area covered compared to the positively charged particles. For negatively charged spray using diesel oil, the increases were 194 percent and 320 percent respectively, for the top and bottom of leaves, compared to coverage with the uncharged sprays. The figures for water were respectively, 224 percent and 203 percent. Another field experiment was reported showing that potato plants treated with copper diluted in water showed higher copper deposits on their leaves for charged sprays and when subjected to rainfall the charged deposits lasted longer than those on the same doses of uncharged chemicals.

Bowen et al. (1964) presented some of the theoretical implications of electric fields on deposition of charged particles. An attempt was made to appraise the limitations and the possible benefits of the process as interpreted
from a study of electric fields of uniform charge density.

Law and Bowen (1966) investigated the electric charge imparted to spray droplets by electrostatic induction. Two conventional pressure nozzles with a flow rate of 4.1 gph (4.31 ml/s) were used. A 1 inch diameter steel sphere was fixed in front the nozzles at about 25/32 inch. This sphere was maintained at potentials up to 16 kV while the nozzles were grounded via the spray boom pipe. Although no influences of the applied potentials on droplet sizes were determined, a maximum average current for the spray discharge was measured as \(-2.70 \times 10^{-6}\) A at an applied potential of +7 kV for a full metallic nozzle. For a nonconductive plastic nozzle with very similar spray characteristics, the maximum spray current of \(-3.6 \times 10^{-6}\) A occurred at +4 kV. It was speculated, based on the assumption that the spray had a uniform distribution diameter of 51 microns, that the charge carried per droplet was \(5.8 \times 10^{-14}\) C, or \(3.6 \times 10^5\) electrons, which corresponds to only 3 percent of the theoretical maximum electric charge that a 51 micron diameter water droplet can hold. The authors also concluded that in order to increase the net charge induced on the droplets, the problem of the opposing ionized field charging from liquid on the induction electrodes would have to be overcome.

Splinter (1968) modified partially the geometry presented by Law and Bowen (1966) and tested the influences of
the electrostatic potentials on different liquids and at different flow rates. The charge to mass ratio was about $5.8 \times 10^{-4}$ C/kg for water, about $2.4 \times 10^{-4}$ C/kg for water with 2.6 g NaCl/liter of water, and $4.4 \times 10^{-4}$ C/kg for DDT emulsion in water, using the ionized field arrangement. For the induction charging arrangement, tests with diesel oil gave no detectable charging, since, theoretically the induction charging requires that the spray be conductive. Also, no apparent effect of surface charge on rates of droplet evaporation were noted.

Law (1976) developed and experimentally analyzed a miniature embedded-electrode charger incorporated into a pneumatic-atomizing nozzle. Droplet charging was imparted by electrostatic induction. Potentials used were within the range of 0.5 to 4.0 kV. The droplet size distribution was based on that from a pneumatic-atomizing spray nozzle manufactured by Spraying Systems Company type SV #22B. No attempt was made to verify the influence of electrostatic potentials on the droplet size distribution. For a liquid flow rate of 73 ml/min the volume mean diameter was assumed to be about 19-20 microns. Droplet charge attained was about 3 percent of the theoretical Rayleigh charge limit, or $2.10^{-14}$ C/droplet, which was derived from the measured spray cloud current of $5.8 \times 10^{-6}$A when a potential of 2.5 kV was applied under a liquid flow rate of 73 ml/min, with a
liquid showing an electric resistivity of $10^4$ ohm-cm. Re-
working these figures a charge to mass ratio of 4.77x$10^{-3}$
C/kg is calculated. As concluded by Law (1976), this
represented approximately 2.4 times the charge on the
particles being charged by the ionized-field particle
charging method used by Law and Bowen (1966) and Splinter
(1968). Law and Bowen (1975) derived equations describing
the evaporation of charged droplets. The effects within a
droplet of surface tension and surface charge upon the
droplet vapor pressure have been described by the equation:

$$\ln\left(\frac{p}{p_0}\right) = \frac{M}{\rho_1 RT} \left[ \frac{2\sigma}{r} - \frac{Q^2}{8\pi\varepsilon_0 r^4} \right]$$  \hspace{1cm} (15)$$

where

- $p$: droplet vapor pressure
- $p_0$: equilibrium vapor pressure of a flat surface of
  liquid at given temperature
- $M$: molar weight of evaporating liquid
- $\rho_1$: liquid specific mass
- $R$: universal gas constant
- $T$: absolute temperature
- $\sigma$: liquid surface tension
- $r$: droplet radius
- $Q$: electric charge attained by droplet
- $\varepsilon_0$: electrical permittivity of the surrounding
  air-liquid vapor medium
A liquid droplet will become unstable and break up into smaller droplets if an attempt is made to charge the droplet beyond the amount where the outward stress due to the surface charge density just equals the inward stress of surface tension. This condition was first calculated by Lord Rayleigh in 1896. Therefore, for the onset of hydrodynamic instability of a charged liquid droplet, the condition is given as

$$\frac{Q^2}{3\pi \varepsilon r^4} = \frac{2\sigma}{r}$$  \hspace{1cm} (16)$$

or, explicitly, the maximum droplet charge that can be attained is

$$Q = 4(\pi \varepsilon \sigma)^{1/2} r^{3/2}$$  \hspace{1cm} (17)$$

This same relation was derived by Vonnegut and Neubauer (1952) using the total energy of the system and by Hendricks and Schneider (1963) using the Lagrange equations to describe small departures from spherical equilibrium configuration of a conducting liquid droplet, based on observations communicated by Lord Rayleigh in 1882. Both derivations are based on the assumptions that: a) the liquid is a conductor, b) no external electric field is applied, and c) the electrical charge on the droplet (surface) remains constant.

Many experiments have shown electrostatic dispersion of
a liquid to be feasible in laboratory conditions with high potentials producing very intense electrostatic fields near or at the points of liquid disruption. Most of these experiments were conducted with extremely low liquid flow rates when compared with practical field requirements for pesticide application.

The attempts made by several workers to electrostatically charge a liquid spray for agricultural purposes have shown some improvement on the degree of recovery of the pesticide applied, although no studies have been carried out to examine the influence on droplet size of an electrostatic potential applied to conventional nozzles. Most of the workers have reported their experimental findings in terms of cloud current or in terms of the electric charge to mass ratio, based on the mean droplet size produced by an equivalent commercial nozzle, or on the droplet size distribution furnished by the manufacturer.

The determination of a spray droplet size distribution can be accomplished in several ways, depending on the availability of existing equipment. In general the special care and techniques required are restricted to laboratory tests; although some experimental work can be done in the field, but at much lower accuracy than can be achieved in laboratories.
III. OBJECTIVES

The overall objective of this study was to investigate the feasibility of applying an electrostatic potential on a rotating disc atomizer for liquid spraying. Specific objectives were as follows:

1. To investigate the influence of electrostatic potentials on droplet size distribution and spray homogeneity;

2. To investigate the influence of electrostatic potentials on the spray pattern;

3. To investigate the influence of electrostatic potentials on the electric charge imparted to the liquid sprayed.
IV. DATA ACQUISITION

To accomplish the objectives proposed, some equipment was designed, constructed, tested, and modified until repeatable and reliable results were achieved. After that the equipment was considered ready for use.

A. Equipment

Two basic pieces of equipment were designed and constructed for the laboratory tests: a rotating disc driver and a high voltage dc power supply.

1. Rotating disc driver

The rotating disc driver had to fulfill the following requirements:

1. have power enough to maintain preset constant speed up to 12000 rpm;
2. have variable speed from 1000 to 12000 rpm, with control within 3 percent;
3. have exchangeable discs;
4. have the shaft electrically insulated from the main frame for potentials up to 60 kV;
5. be capable of operating for long periods of time;
6. accept a brush contacting the rotating shaft at high dc potentials;
7. be installed on a transportable metal frame.

A 1/3 HP 120 volt ac "Skill" router with speed up to 20,000 rpm was used as the prime mover. As sketched in Figure 2 the router was fixed on a metal platform welded to a rectangular steel tube. Bolted to the rectangular tube were two blocks of Plexiglas, each supporting a ball bearing mounted in such a way as to keep the steel shaft electrically insulated from the frame and maintain axial alignment with the router shaft. An intermediate connection 150 millimeter long cut from a 1/4-inch diameter reinforced fiberglass rod was used as the upper part of the mechanical shaft. The fiberglass shaft served as an electrical insulator. A special collet clutch, similar to that used in the router to hold the bit, was used on the metal shaft to connect the fiberglass rod to it and transmit the torque to the rotating discs. Another Plexiglas plate was installed between the frame and the rotating disc to increase the electrical insulation against the influence of the very high electrostatic fields developed around the rotating discs. The discs were fixed to the shaft by a 1/4-inch diameter bolt screwed into the lower end of the rotating shaft. For the potentials applied, the dimensions used were adequate. The only necessary care concerned keeping the
Figure 2. Details of the rotating disc shaft and drive
Plexiglas surfaces clean to avoid excessive current leakage.

The router speed was controlled by a solid-state variable speed control using a triac based circuit, similar to commercially available controllers.

A tachometer was installed to monitor the rotating disc speed. A 12v dc light source was installed close to the router collet clutch, illuminating the hexagonal nut which had a chrome-plated surface measuring 5 mm x 10 mm cemented to one of its faces. By adjusting distance and angle of incidence, the reflected light was received by a phototransistor which activated a Schmitt trigger. The rectangular pulses from the Schmitt-trigger were counted by a Hewlett-Packard Model 5212-A frequency counter.

Figure 3 shows a diagram of the tachometer used. The optical sensor $Q_1$ was a phototransistor, FTP-100. A voltage regulator LM-340-5 was used as the IC2 to maintain compatibility between the 12v dc source used and the recommended input voltage for the TTL IC1, where half of a dual Schmitt trigger 7413 was used. A 500 kΩ potentiometer was used to bias the phototransistor according to the light intensity, to provide a single count per revolution. Output from pin 8 of the IC2 was directed to the frequency counter. The gate time was set at approximately one second, and the frequency counter displayed the rotating disc speed in
Figure 3. Diagram of the tachometer used to monitor the rotating disc speeds

Q₁: Phototransistor FTP-100
IC₁: 1/2 TTL Dual Schmitt Trigger 7313
IC₂: Voltage Regulator, LM-340-5

Hertz. No feedback system was used for automatic speed control. Speed was controlled by reading the frequency counter display and adjusting the potentiometer controlling the router speed.

2. High voltage power supply

The high voltage dc power supply shown in the block diagram of Figure 4 was assembled. Three basic blocks were constructed: a) a timer, or frequency generator, b) a high-
The timer was manufactured by National Semiconductor. The basic device was an IC LM 555V, selected for its low cost and versatility. A two-stage amplifier, diagrammed in Figure 4, was used in the output from the IC LM 555V since currents up to 0.7A were expected from the pulse generator. The pulse generator constructed is shown in Graf and Whalen,
1974. It was decided that a capacitive-discharge ignition system for automobiles with the necessary adaptations, would make a satisfactory pulse generator when connected to an ignition coil. Consequently, a commercial kit from Delta, Model Mark Ten B was assembled. The input signal from the conventional breaker points was replaced by the timer, as shown in Figure 5. Measurements carried out in the laboratory using a high voltage probe, ElCO HVP-2 with $1.09 \times 10^9$ Ω resistance, showed peak-voltages up to 45 kV. The ignition coil used was a commercial heavy duty one. The high voltage pulses from the secondary winding of the ignition coil were driven into a rectifier using five 15 kV, 1 milliampere silicon rectifier connected in series. The rectified current was fed to a set of seven 6 kV, 0.1 μF capacitors connected in series to ground as shown in Figure 5. Each capacitor was connected in parallel to a 240 mΩ resistor. This presented a total resistive load of $1.68 \times 10^9$ Ω to the rectified voltage. The value for the parallel resistances was based on operator safety and the values of voltage and electric charge stored in the capacitors. The internal resistance of the capacitors used was very high. This resistance was not measured but it was observed that the time constant of the system without any shunt resistance was over 24 hours, which represented a nuisance to the
Figure 5. Diagram of the circuit used for the high voltage power supply.
operator. Small values for the parallel resistances were tested but they were discarded because their high current demands dropped the maximum output dc voltage to 18 kV, for resistances of 22 MΩ. When the 240 MΩ resistors were used the time constant for the capacitors was calculated to be about 24 seconds, which seemed very reasonable. The introduction of a complete rectifier bridge between the capacitive-discharge ignition system and the ignition coil allowed the primary winding of the ignition coil to be insulated from ground. Therefore the switch S1 could invert the polarity of the voltage pulse to the ignition coil. When changing the polarity of the rectifier, the stored electric charge on the capacitors was of the opposite polarity in relation to ground. This arrangement was adequate for the experimental work done. Connection of the seven capacitors in series was very useful as a voltage divider. Although seven different values of voltage could be obtained from the power supply described, only three of these were used. Experiments were conducted using both negative and positive polarity.

3. Spray collector and spray sampler

Cloud current is directly related to the electric charge imparted to the spray droplets during the electrostatically assisted atomization. To obtain an accurate measurement of
this current, precise collection of the liquid spray was required. Also, collection of a fraction of the spray along a radial direction was required for the spray droplet size measurement.

To accomplish the first task two metal cylindrically curved surfaces were installed. These were made of aluminum suspended from a fixed frame and were electrically insulated, as shown in Figure 6. One sheet was connected to ground through a picoammeter, RCA Model WV-84C. This sheet was provided with vertical surfaces on both ends to collect all the sprayed liquid produced in a half space around the rotating disc atomizer. The other half surface was directly grounded. The lower ends of these collectors were placed at 200 mm (8 inches) below the rotating disc atomizer, while the upper ends stood about 50 mm (2 inches) higher than the horizontal plane containing the rotating disc. This configuration permitted all the liquid sprayed into each half space to be collected by the respective collecting surface.

The spray sampling for droplet size measurement and droplet size distribution was accomplished by using a variable width window cut along one radial direction in the spray collector, starting from the point immediately below the rotating disc center. A second metal surface curved with the same radius as the spray collector surface was
Figure 6. Details of the suspended spray collectors

Figure 7. Schematics of the spray sampling system
installed on a metal support underneath the spray collector surface, at a distance less or equal to 10 mm. This metal support was fixed on a movable target frame, which was assembled on a pair of fixed metal rails by means of four small wheels. A sketch of the arrangement used is shown in Figure 7. An electric motor coupled to a gear box reducer was used to drive the target frame by means of two pairs of pulleys and two flexible steel cables. The target frame course was limited by a pair of switches which turned off the electric motor and at the same time reset the system to be started again in the opposite direction. The total course of this target frame was about 350 mm. To assure a constant speed the useful part of the course for collecting droplets was approximately 100 mm about the mid-point. A switch was also provided to time the target frame speed for a preset fixed travelled distance of 163 millimeters. A frequency generator using an IC LM 555V and one buffer transistor was used to drive a calculator Texas Instruments TI-1250, modified as a pulse counter. The frequency for the frequency generator was fixed at 20.0 Hz. Readings from the calculator were used to monitor the cover speed.

A place was provided on the metal target frame, as shown in Figure 7, to receive a removable tray, curved with the same shape as the spray collector. This tray was 80 mm
wide and had a sliding house along its 700 mm length to receive card strips 60 mm (2-1/4 inch) wide.

After several preliminary runs, the openings of the slit window were fixed at 54 mm and 15 mm, respectively at the end near the rotating disc center and at the outward one. This was based on a fixed liquid flow of about 1.0 ml/s, disc speeds up to 10,000 rpm, and the target frame speed of about 0.10 m/s, when the selected target was used. The concentration of spots produced by the sprayed liquid droplets was considered adequate for further analysis.

An external polyethylene sheet was used to cover the rotating disc atomizer installation. Two goals were accomplished: to provide protection against fallout dust on the equipment, and to allow control of the relative humidity during spraying tests.

An overall view of the installation and the equipment used is shown in Figures 8a and 8b.

B. Materials and Methods

Distilled water was selected as the liquid to be used throughout these experiments. The reasons were based on the following: 1) it is easy to obtain; 2) its physical properties of interest in this experiment, such as density, viscosity, surface tension and electric conductivity, can be
Figure 8a. Close-up view of the spraying system.

Figure 8b. Overall view with cover installed.
kept within narrow ranges for ambient temperature varying between 20°C to 30°C; 3) it does not present noxious residues or vapors for the operator or for the equipment used; 4) it presents an electric conductivity within the expected optimum range, or about \(1 \times 10^{-6}\) S/cm, according to the CRC Handbook of Chemistry and Physics, Weast (1974); 5) numerous commercial pesticides are water soluble; 6) water is the least expensive and most abundant and reliable of the liquids to be used as carrier for pesticide applications; 7) water, even undyed, is the liquid presenting the easiest way to be sampled for droplet size measurement, by using a water sensitive target.

After selecting the liquid to be used in the experiments, the target for the spray droplets were chosen using the recommendations of Turner and Huntington (1970) and later used by Walker and Walton (1972). The collection procedure is fully explained by Turner and Huntington (1970). A minor variation was the photographic paper used. The method used for sampling the spray droplets consisted of treating a smooth and clear surface with a water sensitive dye. Kodabromide SW-F2, a Kodak photographic paper, 8x11 inches, was fixed and glazed. A dye solution was prepared by dissolving 2g of Bromophenol Blue in 40 ml A.R. Acetone and diluting with 360 ml A.R. Toluene. Individual sheets of the fixed photographic paper, held by means of a pincers, were immersed
and slowly moved into the dye solution for 20 seconds. The papers were removed with the pincers and were then suspended by clothespins from a taut line until complete drying was achieved. To prevent fingerprints, polyethylene gloves were used. The treated sheets of paper were then cut in strips 50 mm (2 inches) wide, and placed inside polyethylene bags to avoid moisture contamination. Although these could be stored for several days without problems, only the number of strips that would be used in two to three days were prepared at one time. The treated strip papers were stuck to heavy cardboard strips measuring 63 x 711 mm (2-1/2 x 28 inches), by means of a double-face tape. These constituted the targets used during the experimental work in sampling the sprayed liquid for droplet size. The blue stains produced when the water droplets contacted the dyed target were measured, after first washing out the excess of Bromophenol Blue with Ethyl Acetate.

A calibration conducted in the laboratory to correlate the stain diameters produced by water droplets showed very close agreement with the experimental curve of Turner and Huntington (1970) and shown in Figure 9. A regression equation, with a correlation coefficient $r^2 = 0.995$, was derived from the experimental points as
Figure 9. Calibration curve of the water sensitive dyed target
\[ d = 1.145 s^{0.8675} \]  

where

- \( d \): diameter of the water droplet, in microns,
- \( s \): stain diameter produced on the target by a droplet of diameter \( d \), in microns.

Equation 11 was used to compute droplet sizes from the measured stain diameters.

The total current drawn from the HV power supply was read from a microammeter installed between ground and the ground terminal of the storage capacitors.

The disc current was measured by a microammeter with a field effect transistor in the input to allow measurement of currents down to 1 microampere. The scales used were 1.0, 5.0, 10 and 50.0 microamperes. The drift was small after a few seconds of instrument warming. It was possible to adjust the zero of the scale at any time, even with a high potential applied to the disc. The ammeter was installed in a small aluminum box, which was screwed to a narrow Plexiglas plate attached to the main frame holding the rotating disc atomizer driver.

The cloud current was measured by a portable, battery operated picoammeter, RCA Model WV-84C, connected between half of the spray collector and the ground.

The applied voltage was measured by means of a high
voltage probe, ELCO HVP-2 with 1090 MΩ resistance, connected to a 50 microampere full scale ammeter.

All of these ammeters were provided with switches to invert the readings for reversed input polarity.

The liquid flow was maintained at about 1.0 ml/s. This value was selected as a practical rate for ULV application. It represents the flow rate from a single atomizer covering a span 1 m wide traveling at 2 m/s and would apply 20 liters per hectare of liquid spray. To control the flow rate a small container of 80 ml capacity was used, and the total liquid head from the discharge tube onto the rotating disc atomizer was set to the point where the measured flow rate was approximately 1.0 ml/s. Variations observed during the tests were probably caused by variations in temperature, which affected the liquid viscosity. The flow rate values were calculated from the time required to drain a fixed volume of liquid from the container, which had a volume scale on the transparent cylindrical walls.

The ambient conditions inside the cover were determined by readings of dry bulb and wet bulb temperatures from two thermometers placed in front of a small electric fan. This provided limited air circulation around the thermometers with negligible effects on the spray deposition.
Three discs were used for tests. These are shown in Figure 10.

Disc 2
- Diameter: 50.4mm
- 4 vanes
- Height: 2.9mm

Disc 3
- Diameter: 67mm
- Flat

Disc 4
- Diameter: 67mm
- 8 vanes
- Height: 5mm

Figure 10. Sketch of the discs used

C. Test Procedure

All of the design variables were under control except for the dry bulb temperature and the wet bulb temperature which varied from day to day. To minimize these variations tests were run only during favorable ambient conditions. The covering of the rotating disc atomizer system with a plastic cover provided effective control of the relative
humidity, which was kept approximately between 75 to 80 percent, with dry bulb temperatures in the range of 26°C to 31.7°C.

For every experimental run the liquid reservoir was filled, the target tray was placed on the target frame located at the same end of its course of travel. In that position the targets were fully protected from the spray droplets being produced by the atomizer. The ammeters were turned on at the correct polarity and were set to the optimum scale. If noticeable leakage currents that could affect the results were detected, the system was turned off and the affected surfaces were cleaned with isopropyl alcohol and facial tissue until the system was considered ready for the test run. In accordance with the experimental design, the potential polarity, and speed were set. In general, the polarity was fixed for all runs with the same disc, and was then switched to the opposite polarity. Also, all tests on one disc were run in sequence. This procedure was dictated in part by the difficulty of changing discs at random, and also because it was expected that the treatment "discs" would constitute a block.

The timer (stop watch) was reset to zero before every timing event. With the solenoid valve closed the rotating disc was brought up to the operating speed. The high voltage
power supply was turned on, except for the zero applied voltage tests. Also, a switch installed in the high voltage line was closed after verification of the correct potential and polarity selected for the run. The solenoid valve was turned on and liquid was allowed to flow onto the rotating disc, starting the spraying process. Liquid discharge flow was timed by the same stop watch used to time the target frame speed. When the liquid free surface in the small reservoir crossed the line corresponding to 80 ml volume the stop watch was turned on until the volume of the discharged liquid was 40 ml. This represented a variation of about 3 cm in the total liquid head, originally started from approximately 38 cm. The average flow rate for the 40 ml discharged was calculated. Values of total current, disc current, and cloud current were recorded, as well as the speed of the rotating disc, the applied potential, and the time required to discharge 40 ml of liquid. The stop watch was reset and the target frame was triggered to move underneath the spray collector through the window opening. The target frame stopped at the other extreme of its course beneath the spray cover. The system was turned off, and the target frame travel time between two fixed points placed 16.3 cm apart was recorded from the stopwatch. The target tray was removed and the target strip was replaced by a new unexposed one. The target frame was returned to its initial
extremity and the target tray was again reinstalled. Dry
bulb and wet bulb temperatures were recorded. The process
was repeated until both polarities were tested at the
three voltage levels for all three discs. The applied
potentials were 0V, +8 kV, +22 kV, -8 kV, and -22 kV.
For spray charging purposes, cloud current, disc current
and total current were measured also for the potentials of
+15 kV and -15 kV, but droplet size measurements were not
made at these potentials.

D. Experimental Design

A factorial experiment was planned. This was justi-
fied because all factors were independent, and a complete
analysis of the factor effects would be possible.

A 3 x 3 x 5 factorial was used in the experiment. The
three discs used can be considered a three level treatment,
called disc 2, disc 3, and disc 4. The factor speed was also
applied at three levels: 50 Hz, 100 Hz, and 150 Hz. These
were the angular velocities of the rotating disc atomizers.
The factor potential was applied at seven different levels,
as: -22 kV, -15 kV, -8 kV, 0 kV, 8 kV, 15 kV, and 22 kV.
However, sampling for droplet size analysis was not done for
-15 kV and 15 kV. The two other factors, liquid and liquid
flow rate were each fixed at a single level. Reasons for
this where explained previously. Water is one of the most common pesticide carriers, and the fixed flow at the approximate rate of 1 ml/s represents a very acceptable rate for ULV applications. These constituted the design variables for the experiment. A single replication was used due to time and resource limitations. According to Ostle and Mensing (1975) this is valid for small experimental errors encountered in industrial experiments. In such cases, the experimental error is estimated by pooling the mean squares associated with the higher order interactions, which is equivalent to assuming that the true higher order interaction effects are zero.

Effects of spray charging are indicated by the electric charge flow rates, or electric currents. Currents of interest are the total current furnished by the high voltage power supply, the disc current furnished by the HV power supply and released by the rotating disc atomizer, and the cloud current, representing the flow of electric charger carried by the spray droplets.

To study the influences of the experimental factors on the droplet size distribution and spray dispersion factor, only five levels of applied potential were used, -22 kV, -15 kV, 0 kV, 8 kV, and 22 kV. Six stations representing randomized blocks were established in the sampling target,
and droplet counting and sizing was performed for these locations. These stations were assigned on each sampling target in a consistent way, such that station No. 1 was always set at the farthest end of the target, and generally collected the largest droplets. Station No. 6 was always placed 10 centimeters from the target end laying beneath the rotating disc atomizer. The other stations were approximately equally spaced between the first and the last stations.

Each treatment constituted a single experimental unit. Treatment effects were determined by means of appropriate transformations on the raw data, corresponding to the spot size distributions and concentration on the sampled targets.

The environmental parameters affecting the experiment, dry bulb temperature, relative humidity and air velocity, were controlled within close limits to avoid having to correct for these factors.
V. RESULTS

The raw data was appropriately processed and two basic groups of data were established. The first group is related to the electric charge imparted to the spray, while the second group is related to the spray sampling for posterior determination of droplet size distribution.

A. Spray Charging Characteristics

The liquid flow rate was expressed in milliliters per second (ml/s) and the applied potentials were expressed in kilovolts (kV). The complete table of data is shown in Appendix A. The cloud current is plotted versus applied potentials in Figures 11, 12 and 13, for disc 2, disc 3, and disc 4 respectively. The discs are sketched in Figure 10.

B. Droplet Size Characteristics

After exposure to the liquid spray during the tests, the target strips were treated with Ethyl Acetate to remove the excess of Bromophenol Blue. That treatment was recommended to protect against any further moisture effects on the water sensitive dye used, and also to improve the contrast between the light blue spots left on the dyed target and the washed background. Every target was marked at six points
Figure 11. Relationship between cloud current and applied potentials for disc 2
Figure 12. Relationship between cloud current and applied potential for disc 3
Figure 13. Relationship between cloud current and applied potentials for disc 4
(stations) along its length. No fixed distances were imposed on each target, since the maximum penetration of the droplets was a function of the rotating disc size and speed. However, the assigned station 1 was always very close to the furthest droplet deposition on each target, and the last one, station 6, was always about 10 cm from the lower end of the target in the center of the spray pattern. In general, the intermediate stations, stations 2, 3, 4, and 5, were equally spaced between stations 1 and 6. The distances from the center of the spray pattern were recorded for all stations. A full scale photograph of each station was taken. This was accomplished by using a stand which held the camera at a fixed position. Illumination was provided by two 150 watt photoflood lamp. The camera used was a Canon model FTb, with fixed extension tubes and the regular Canon 50 mm focal length, f 1.8 lens. Although a black and white high contrast copy film, Kodak 5069, was tested, the best results were obtained from Kodalith Ortho Type 3, 35 mm film, using a polarizer filter with the polarizing axes crossed to reduce reflections and glare from the target surface. The Kodalith film sensitivity was 6 ASA. After some trials, the shutter speed was fixed at 1 second and the lens aperture was set at f 7. It was observed that variations of more than one-half an f-stop affected droplet
sizing results, confirming Liljedahl's (1971) findings. The exposed and processed negatives where then enlarged up to a maximum size of 8x11 inches.

Different enlargements where used as a function of the spot sizes found in the negatives. These were 7.5X, 10X, 15X, 20X, 22.5X, and 33X. The enlargement was based on the minimum and maximum size of the enlarged spots, fixed at 0.3 mm and 9.2 mm, respectively, for use with a semi-automatic particle size analyzer, Carl Zeiss, Model TGZ-3. A second limitation was the enlarging equipment available. The best results for the enlarged pictures were obtained when Kodabromide SW F5, and F6 photographic paper were used. The choice of a single weight paper was imposed by the semi-automatic particle size analyzer used, where the spot is sized by a spotlight of variable diameter, focused through the photographic paper. Detailed information is found in the apparatus manual and in the bulletin published by Carl Zeiss Inc. (1956). Every picture corresponding to a collection station was analyzed and the results were recorded from the particle size analyzer. The number of spots with a diameter within the limits of a certain class was added to that class counter. The total number of scanned classes from 0.2 mm diameter up to 9.2 mm diameter was 48, equally spaced according to an arithmetic progression.
In general, for a single picture, less than 20 classes contained one or more particle counts. Preliminary tests showed the adequacy of this method, based on the spot population per enlarged picture and the natural dispersion of the spot sizes. The criteria established by Montgomery (1964) were used, which stated that the required number of measurements and their expected accuracy depend on the range of sizes. A graph, as shown in Figure 14, provided a guide to the number of spots that must be measured to achieve an accuracy for the count median diameter to within ±10 percent at the 99 percent confidence level, after calculation of the parameter \((d_{100} - d_0)/d_{50}\) for the lower curve. By the same token, the upper curve shown in Figure 14 permitted estimation of the droplet sizes representing the 10th and 90th percentiles, respectively, to within ±10 percent accuracy at the 99 confidence level, by using respectively the parameter, \((d_{50} - d_0)/d_{10}\), and \((d_{100} - d_{50})/d_{90}\).

A few discrepancies occurred in droplet size distribution for single station estimations, mainly for disc 2 at stations 1 and 2, although overall estimation of the droplet size distribution per run was accomplished with good accuracy. The concept of stratified sampling as explained in Silverman et al. (1971) and Stockham and Fochtman (1977) was used when establishing the droplet size distribution for an
Figure 14. Measurements required for the count median diameter and the 10th and 90th percentiles to within ± 10% accuracy at 99% confidence level (after Montgomery, 1964)

In Figure 14, the parameters used correspond to the midpoint of the classes as:

- $d_0$: where the smallest particle is found;
- $d_{10}$: where the first 10 percent of the particles are found,
- $d_{50}$: where the first 50 percent of the particles are found,
- $d_{90}$: where the first 90 percent of the particles are found,
- $d_{100}$: where the largest particle is found
individual run, since, in general there exists a relationship between the particle size distribution and the distance from the rotating disc atomizer. The outermost stations collected the largest droplets, and the enlargements used were less than those used for inner stations which exhibited larger numbers but smaller droplets. In general, different station areas were sampled to obtain the final spray droplet distribution per run. Appendix B shows the raw data obtained from each individual run. The enlargement used for the picture taken from each station is listed. Only the nonzero counting classes were considered, as they were furnished by the semi-automatic particle size analyzer. The tables show the corresponding data of the six stations for each run.

The raw data, as shown in Appendix B, was transformed by means of Equation 11, after considering the enlargement of the spots measured. A second transformation was introduced in order to reduce the number of droplet size classes. This transformation was used in the computer program shown in Appendix C as the subroutine XCLASS. It was based on the assumption that the spots counted within each class were uniformly distributed in the range of the class interval with respect to the spot diameters. The selection of 25 classes to cover the range from 10 microns up to 720 microns
according to a geometric scale was based on the dispersion of the droplet spectra for the experimental units and the number of droplets counted in each of the new transformed classes. Comparisons of the means and standard deviations obtained directly from the data after the first transformation with those from the 25-class transformation showed negligible differences. Calculations of the moments, the skewness, and the kurtosis for both distribution arrangements also showed very small differences. Therefore, the droplet size distributions for all the treatments were based on the data after transformation into the 25 classes. A total of 270 stations were sampled. One table for each station was prepared, showing the basic frequency distribution and the cumulative distribution of droplets by number and by volume. In addition, other parameters were calculated for further statistical analyzer. Some of this information is presented in Appendix D to illustrate the procedures.

Two transformations were made on the droplet size distributions by station, and these were made by the computer program shown in Appendix C. Both transformations are related to the overall droplet size distribution per run. The first transformation yielded a new distribution called sum distribution. The same 25 class intervals was used, and the corresponding classes were summed through the six sampled
stations. This new distribution represents the droplet distribution that would be expected if a sampling device were allowed to move along a radial direction during the spraying process. The travel speed would be such as to produce on the water sensitive target the same concentration of droplets as in the sum distribution. These sum distributions are presented in Appendix E, together with their corresponding means, standard deviations, and other statistical parameters.

The second transformation, called radial distribution, added the frequencies of the corresponding classes through the six sampled stations according to the radial distance of each class relative to the radial distance of station 1. Mathematically it represented the transformation of a distribution on the xy-plane to a new radial distribution on the rθ-plane, with r the Jacobian of such a transformation. Physically it represented the expected droplet size distribution for the rotating disc atomizer, as tested. This transformation was an alternative to the first one, and was calculated by the computer program of Appendix C. Appendix F shows the radial distribution for individual runs.

Several characteristic diameters were calculated by means of the computer program shown in Appendix C, to represent the droplet size means for the spray distributions.
These diameters, and others not treated, are discussed in Mugele and Evans (1951), Marshall (1954), Liljedahl (1971), Silverman et al. (1971), Dennis (1976), Goering and Smith (1976), and Stockham and Fochtman (1977).

The calculated mean diameters and corresponding standard deviation were calculated from the following equations:

\[
D_N = \frac{\sum n_i D_i}{\sum n_i} \quad (19)
\]

\[
s_N = \frac{\sum n_i D_i^2 - (\sum n_i D_i)^2 / \sum n_i}{(\sum n_i - 1)} \quad (20)
\]

where \(D_N\) is the number mean diameter and \(s_N\) is the corresponding number standard deviation.

\[
D_{VME} = \left(\frac{\sum n_i D_i^3}{\sum n_i}\right)^{1/3} \quad (21)
\]

where \(D_{VME}\) is the Mugele-Evans volume mean diameter.

\[
D_{VHE} = \frac{\sum n_i D_i^4}{\sum n_i D_i^3} \quad (22)
\]

where \(D_{VHE}\) is the Herdan volume distribution mean diameter.

This characteristic diameter is useful in studies involving liquid evaporation and molecular diffusion.

The Sauter mean diameter, \(D_{Saut}\) or \(D_{sv}\), as calculated by Equation 23, is employed in studies related to heat and mass transfer through the droplet surface, as represented by evaporation and drying, combustion, and other chemical reactions.
The surface mean diameters, given by Equation 24, is useful for absorption studies.

\[ D_{saut} = D_{sv} = \frac{(\Sigma n_i D_i^3)}{\Sigma n_i D_i^2} \]  

Where \( D_{saut} \) is the surface mean diameter.

Because many drop size distributions are approximately normal with respect to the logarithm of the size, the logarithmic-normal distribution is frequently assumed in their analysis. The mean computed from the logarithmic transformed data is known as the geometric mean. It can also be computed from the number distribution as well or from the volume distribution, as shown by Equations 25 and 26.

\[ D_{gN} = \exp\left(\frac{\Sigma n_i (ln D_i)}{\Sigma n_i}\right) \]  

\[ D_{gv} = \exp\left(\frac{\Sigma n_i D_i^3 (ln D_i)}{\Sigma n_i D_i^3}\right) \]  

Where \( D_{gN} \) is the geometric number mean diameter, and \( D_{gv} \) is the geometric volume mean diameter. The corresponding standard deviation for Equations 21 through 26 were included in the computer program shown in Appendix C.
VI. DISCUSSION

A. Spray Charging Process

Data from the spray charging experiments was analyzed in accordance with standard procedures. The corresponding analysis of variance was conducted according to the procedures of Barr et al. (1976), using the Statistical Analysis System. The treatment potential was highly correlated with the disc current and the cloud current, as would be expected. No regression analysis was made, since the graphs shown in Figures 11 through 13 are based on only three points. Any attempt to extend the results beyond the range of variables studied is not recommended, since as the applied potential increases so does the current through the rotating disc. The reason for this is that the corona discharge exhibits a nonlinear relationship with the electric (electrostatic) field generated close to the rotating disc sharp edges. This electric field is directly related to the applied potential.

The values shown for the cloud current should be smaller than or equal to the disc current. Some of them are slightly greater than the disc current. This resulted from experimental error or localized variations, since the cloud current values were obtained by collecting theoretically half of the liquid sprayed. During short time intervals the liquid
discharge was not always perfectly distributed around the circular area.

The cloud currents observed for the negative polarity were generally higher than the cloud currents for the positive polarity. The same was found for the disc currents. This suggests that negative polarity would be recommended rather than the positive one.

The ratio, cloud current to disc current, was very high, which indicates a high efficiency in the electric charging transfer mechanism, especially at lower potentials, although only a small fraction of the theoretical maximum electric charge per droplet as given by Equation 17, was achieved. The ratio \( q/m \), the amount of electric charge imparted to the mass of liquid sprayed per unit time, for the experiment is shown in Figures 15, 16 and 17, respectively for disc 2, disc 3, and disc 4.

Using Equation 17 the maximum electric charge that a spray could achieve was calculated as

\[
Q_{\text{max}} = \sqrt{\frac{4\pi e}{g}} \sum n_i (r_i)^{3/2}
\]

For disc 2 at 6000 rpm and with a potential of -22 kV applied the efficiency found for the electric charging process was 3.22%. This value is of the same order, but slightly higher than the 3% value presented by Law (1976)
Figure 15. Relationship between electric charge per unit mass and applied potential for disc 2
Figure 16. Relationship between electric charge per unit mass and applied potential for disc 3
Figure 17. Relationship between electric charge per unit mass and applied potential for disc 4.
when using an electrostatic induction spray-charging nozzle system.

For ease of comparisons between theoretical and experimental values, the calculation of an equivalent geometric mean diameter is suggested, as

\[ d_{1.5} = (\sum n_i d_i^{1.5}) \sum n_i \]  \hspace{1cm} (28)

This \( d_{1.5} \) value would be between the number mean diameter as given by Equation 19 and the surface mean diameter as given by Equation 24. The use of the number mean diameter results in smaller values for the maximum electric charge of a single droplet, although the ratio between experimental and theoretical values also would be smaller than the correct one. Calculations performed for disc 4, at 9000 rpm and with a potential of -22 kV, showed charging efficiencies of 9.35% and 7.86%, when the theoretical value of the maximum electric charge was based on \( d_{1.5} \) and \( d_N \), respectively. These values are higher than those shown by Law and Bowen (1966), Splinter (1968), and Law (1976). The difference is probably due to the charging mechanisms used. The induction system used by those investigators are not as efficient as the contact and corona charging mechanism.

While potential was the most significant parameter,
the other two, speed and disc, had significant influence on the cloud current and the ratio q/m. Increasing speed consistently increased the cloud and disc currents for potentials up to 15 kV for both negative and positive polarities. For the highest potential, 22 kV, some erratic results occurred. Corona discharge provides the most likely explanation. Its effect overcame the droplet formation mechanisms. The differences among discs were expected, since the three discs used had different design characteristics.

B. Droplet Size Distribution

The three different discs used produced droplets with different size distributions, as expected. The three discs could be considered as three distinct blocks and could be analyzed independently from each other. Not doing this is probably primarily responsible for the high values of the higher-order interactions recorded. Therefore, the reliability of the analysis of variances of the droplet size distributions is questionable, since it was assumed that the sum of squares of the higher order interactions would be small and that a single replication would be satisfactory. Tables 2 and 3 show respectively the results of the ANOVA for the variable number mean diameter, calculated according
### Table 2. ANOVA for the variable DMN, number mean diameter for sum distribution

<table>
<thead>
<tr>
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<th>Mean Squares</th>
</tr>
</thead>
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<td>102.56</td>
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<tr>
<td>Error</td>
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<td>0.0</td>
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<tr>
<td>Corrected Total</td>
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<td>4512.6</td>
<td></td>
</tr>
</tbody>
</table>

Tests of hypotheses using the ANOVA SS for DISC*POT*SPEED as an error term

<table>
<thead>
<tr>
<th>Source</th>
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<th>ANOVA SS</th>
<th>F-Value</th>
<th>PR &gt; F</th>
</tr>
</thead>
<tbody>
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<td>.0001</td>
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<tr>
<td>PDI</td>
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<td>448.6</td>
<td>3.28</td>
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<tr>
<td>DISC*POT</td>
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<td>245.6</td>
<td>1.88</td>
<td>.1852</td>
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<tr>
<td>SPEED</td>
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<td>0.90</td>
<td>.5399</td>
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<tr>
<td>DISC*SPEED</td>
<td>4</td>
<td>432.3</td>
<td>3.16</td>
<td>.0428</td>
</tr>
<tr>
<td>POT*SPEED</td>
<td>8</td>
<td>546.0</td>
<td>2.00</td>
<td>.1135</td>
</tr>
<tr>
<td>DISC<em>POT</em>SPEED</td>
<td>16</td>
<td>546.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. ANOVA for the variable $D_{aut}$, Sauter mean diameter for sum distribution

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>3943.7</td>
<td>29.6</td>
</tr>
<tr>
<td>Error</td>
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<tr>
<td>Corrected Total</td>
<td>44</td>
<td>3943.7</td>
<td></td>
</tr>
</tbody>
</table>

Tests of hypotheses using the ANOVA SS for DISC*POT*SPEED as an error term

<table>
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<th>DF</th>
<th>ANOVA SS</th>
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<th>PR &gt; F</th>
</tr>
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<td>1651.7</td>
<td>27.07</td>
<td>.0001</td>
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<tr>
<td>POT</td>
<td>4</td>
<td>330.1</td>
<td>2.70</td>
<td>.0678</td>
</tr>
<tr>
<td>DISC*POT</td>
<td>8</td>
<td>250.8</td>
<td>4.79</td>
<td>.0234</td>
</tr>
<tr>
<td>SPEED</td>
<td>2</td>
<td>292.5</td>
<td>1.03</td>
<td>.4553</td>
</tr>
<tr>
<td>DISC*SPEED</td>
<td>4</td>
<td>483.2</td>
<td>3.96</td>
<td>.0203</td>
</tr>
<tr>
<td>POT*SPEED</td>
<td>8</td>
<td>447.3</td>
<td>1.83</td>
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</tr>
<tr>
<td>DISC<em>POT</em>SPEED</td>
<td>16</td>
<td>488.1</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
to Equation 19, and the ANOVA for the variable Sauter mean diameter calculated according to Equation 23 for the sum distribution. In both cases the contribution of the higher order interaction (disc*potential*speed) to the sum of squares is about 12.1 percent, which is not negligible. Therefore, the influences of the treatment potential, although present, cannot be assumed to be responsible for the mean diameter variations which occurred in the spray droplet distributions.

Analyses from separate discs showed a less marked influence of the potential treatment, since the second order interaction, speed potential was in general highly significant for the variables of interest. Its contribution to the sum of squares was about the same order of magnitude, and often, even larger than the contributions from the main factors, as potential and speed.

For the radial distributions similar responses were obtained for the mean values of the different droplet sizes analyzed. The factors disc and speed were the two most significant parameters. Also, separate disc analyses showed the interactions speed*potential for the variables studied was in general very high, with the sum of squares contribution about the same order or even larger than the contribution from the factor potential, except for disc 2. For disc
2 the variables number mean diameter and the logarithmic number mean diameter as calculated by Equations 19 and 25, respectively, showed the factor potential significant at the 6 percent level.

A further analysis of variance was conducted to analyze the influence of the factor potentials on the spray distribution. A cut-off in the lower tail of the droplet size distribution for the radial distribution at class 15 was provided. A new distribution with droplet diameters smaller than 115 microns was obtained and analyzed. The ANOVA for the complete experiment is shown in Table 4, for the variable Mugele-Evans volume mean diameter calculated by Equation 21. Disc 2 under this new cut-off distribution showed a larger influence from the factor potential than the influence exerted by the factor speed, for the variables number mean diameter, logarithmic number mean diameter, Mugele-Evans volume mean diameter, and the Sauter mean diameter, although the levels of significance were respectively 5.7, 4.0, 10.0, and 17.0 percent.

Analyses of variance of the lower tail of the droplet size distributions, including station as a factor were conducted. The three discs were considered individually. The cut-off was made at class 15, which produced new droplet distributions for droplet diameters smaller than 119 microns.
Table 4. ANOVA for the variable $D_{VME}$, Mugele-Evans volume mean diameter, for the radial distribution

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>44</td>
<td>7265.0</td>
<td>165.1</td>
</tr>
<tr>
<td>Error</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>44</td>
<td>7265.0</td>
<td></td>
</tr>
</tbody>
</table>

Tests of hypotheses using the ANOVA SS for DISC*POT*SPEED as an error term

<table>
<thead>
<tr>
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<th>DF</th>
<th>ANOVA SS</th>
<th>F-Value</th>
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</thead>
<tbody>
<tr>
<td>Disc</td>
<td>2</td>
<td>3366.4</td>
<td>31.35</td>
<td>.0001</td>
</tr>
<tr>
<td>Pot</td>
<td>4</td>
<td>655.8</td>
<td>3.05</td>
<td>.0477</td>
</tr>
<tr>
<td>DISC*POT</td>
<td>8</td>
<td>640.4</td>
<td>1.49</td>
<td>.2359</td>
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<tr>
<td>SPEED</td>
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<td>751.3</td>
<td>7.00</td>
<td>.0066</td>
</tr>
<tr>
<td>DISC*SPEED</td>
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<td>556.0</td>
<td>2.59</td>
<td>.0764</td>
</tr>
<tr>
<td>POT*SPEED</td>
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<td>436.1</td>
<td>1.02</td>
<td>.4628</td>
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<tr>
<td>DISC<em>POT</em>SPEED</td>
<td>16</td>
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<td></td>
</tr>
</tbody>
</table>
The ANOVA for disc 2 is shown in Table 5. In this case, for the Sauter diameter, potential is a nonsignificant main factor. However, the interactions POT*SPEED and POT*STATION are significant. This means that potential has influenced in some way the droplet distribution through the stations, or, in other words, through the radial direction. The interaction POT*SPEED is significant based on the fact that the droplet size is highly affected by the rotating disc speed. The previous analysis of disc 3 data showed that the Migele-Evans volume mean diameter was affected by the factor potential and its interactions. The corresponding linear model was tested through the third-order interaction, and the ANOVA is shown in Table 6.

Disc 4 was analyzed by the same method, and showed significant differences for the variables Mugele-Evans volume mean diameter, Sauter diameter, logarithmic number mean diameter, and number mean diameter for the main factor potential and speed, as well as for the second order interaction potential*speed for the lower tail of the droplet size distributions up to 119 micron droplet diameter.

In spite of the statistically significant differences found for the lower tail of the droplet distributions for some of the variables, the plots of the mean values show an erratic behavior with the potential levels, and a regression
Table 5. ANOVA for the variable $D_{\text{saut}}$, the Sauter diameter, using a linear model on droplet diameters smaller than 119 microns for disc 2

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F-Value</th>
<th>PR &gt; F</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
<td>49</td>
<td>33542.9</td>
<td>684.5</td>
<td>4.33</td>
<td>.0001</td>
<td>.88</td>
</tr>
<tr>
<td>Error</td>
<td>29</td>
<td>4587.1</td>
<td>158.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>78</td>
<td>38130.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tests of hypotheses using the ANOVA MS for SPEED*STATION*POT as an error term

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>ANOVA SS</th>
<th>F-Value</th>
<th>PR &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot</td>
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<td>170.1</td>
<td>.27</td>
<td>.8956</td>
</tr>
<tr>
<td>Speed</td>
<td>2</td>
<td>282.0</td>
<td>.89</td>
<td>.4210</td>
</tr>
<tr>
<td>POT*SPEED</td>
<td>8</td>
<td>2411.0</td>
<td>1.91</td>
<td>.0946</td>
</tr>
<tr>
<td>STATION</td>
<td>5</td>
<td>16382.0</td>
<td>20.71</td>
<td>.0001</td>
</tr>
<tr>
<td>POT*STATION</td>
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<td>7482.1</td>
<td>2.37</td>
<td>.0017</td>
</tr>
<tr>
<td>SPEED*STATION</td>
<td>10</td>
<td>6814.6</td>
<td>4.31</td>
<td>.0010</td>
</tr>
</tbody>
</table>
Table 6. ANOVA for the variable $D_{VMB}$, the Mugele-Evans volume mean diameter for disc 3, using a linear model, and droplet diameter smaller than 119 microns

<table>
<thead>
<tr>
<th>Source</th>
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<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F-Value</th>
<th>PR</th>
<th>F</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
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<td>36725.0</td>
<td>749.5</td>
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<td>.0001</td>
<td>.965</td>
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</tr>
<tr>
<td>Error</td>
<td>29</td>
<td>1344.0</td>
<td>46.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tests of hypotheses using the ANOVA MS for SPEED*STATION*POT as an error term

<table>
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<tr>
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<th>F-Value</th>
<th>PR &gt; F</th>
</tr>
</thead>
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<td>POT</td>
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<td>1749.1</td>
<td>9.44</td>
<td>.0001</td>
</tr>
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<td>SPEED</td>
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<td>897.0</td>
<td>9.68</td>
<td>.0006</td>
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<td>POT*SPEED</td>
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<td>5373.8</td>
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<td>.0001</td>
</tr>
<tr>
<td>STATION</td>
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<td>POT*STATION</td>
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<td>8124.0</td>
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<td>.0001</td>
</tr>
<tr>
<td>SPEED*STATION</td>
<td>10</td>
<td>8571.8</td>
<td>18.50</td>
<td>.0001</td>
</tr>
</tbody>
</table>
Figure 18. Influence of the applied potential on the volume mean diameter for droplets smaller than 119 microns
analysis would be meaningless. One example is shown in Figure 18, where the variable $D_{VME}$, Mugele-Evans volume mean diameter, represents the mean values of the lower tail of the droplets smaller than 119 microns in diameter.

1. **Degree of dispersion**

Masters and Mohtadi (1967) defined a dispersion factor, $\delta$, as

$$\delta = \frac{d_{0.95} - d_{0.05}}{d_{sv}}$$

(28)

where

- $d_{0.95}$ is the droplet diameter representing the first 95 percent of the cumulative distribution volume;
- $d_{0.05}$ is the droplet diameter representing the first 5 percent of the cumulative distribution volume;
- $d_{sv}$ is the Sauter diameter.

To avoid calculations associated with the Sauter diameter, a new dispersion coefficient, $\alpha$, was defined as

$$\alpha = \frac{d_{0.95} - d_{0.05}}{d_{0.50}}$$

(29)

where $d_{0.05}$ and $d_{0.95}$ are defined as in Equation 28, and the $d_{0.50}$ is the volume median diameter for the distribution, which can be estimated by the geometric volume mean diameter, according to Stockham and Fochtman (1977) if the particle distribution follows a log-normal distribution.
The most practical method is to use log-probability paper, and after plotting the cumulative volume distribution the three parameters $d_{0.05}$, $d_{0.50}$, and $d_{0.95}$ can be graphically determined. Otherwise a computer program can be used to obtain the necessary interpolation in estimating these parameters from numerical data. In this case Equation 29 would present the same degree of difficulty as Equation 28, and both would result in similar values for the dispersion coefficient. The use of such a dispersion coefficient is justified for droplet size distributions that are not log-normally distributed. Furthermore, it can be applied to any distribution. If the particle size distribution follows a log-normal distribution, then the geometric standard deviation is the best estimator for the dispersion coefficient.

It was assumed that the droplet size distributions would follow a log-normal distribution, based on previous information from Marshall (1954), Liljedahl (1971) and Goering and Smith (1976). The dispersion coefficients were calculated using Equation 29 for the experimental distributions, and are presented in Appendix G, for both, sum and radial distributions. Figures 19 to 21 present plots of diameters $d_{0.05}$ and $d_{0.95}$ for the radial distribution versus applied potentials for disc 2, disc 3, and disc 4,
Figure 19. Droplet sizes for 5% and 95% cumulative volume of radial distribution for disc 2 as function of applied potential.
Figure 20. Droplet sizes for 5% and 95% cumulative volume of radial distribution for disc 3 as function of applied potential.
Figure 21. Droplet sizes for 5% and 95% cumulative volume of radial distribution for disc 4 as function of applied potential.
respectively. Figures 22 to 24 do the same, but for the sum distributions.

It can be observed that the factors potential and speed influence the diameters for the first 5 percent volume and the first 95 percent volume in a more consistent way than was found when studying their influence on the distribution formed by cutting off tails of the distributions. Figure 25 shows the dispersion coefficient $\alpha$, calculated by Equation 29, plotted against the applied potentials on the rotating discs for the radial distributions. No strong conclusions can be drawn from these data, although some influence of the factors disc, speed, and potential can be noted. Except for disc 4 rotating at 150 Hz, all the point estimates for the dispersion coefficient lie between the values of 0.5 to 1.15, which means that the rotating disc atomizers and the treatments applied produced a spray of fairly homogeneous droplet size within the range from 5 percent to 95 percent volume of the liquid sprayed.

The values of the dispersion coefficient $\alpha$ were plotted versus the calculated values of the geometric standard deviation, as shown in Figures 26 and 27, for the radial and sum distributions. Linear regression analyses were carried out for the data and the region lines and regression equations
Figure 22. Droplet sizes for 5% and 95% cumulative volume of sum distribution for disc 2 as function of applied potential.
Legend:

- \( \nabla \) - 50 Hz
- \( \bigcirc \) - 100 Hz
- \( \square \) - 150 Hz

- - D.05
- --- - D.95

Figure 23. Droplet sizes for 5% and 95% cumulative volume of sum distribution for disc 3 as function of applied potential.
Figure 24. Droplet sizes for 5% and 95% cumulative volume of sum distribution for disc 4 as function of applied potential.
Figure 25. Dispersion coefficient $\alpha$ for the radial distribution, calculated by equation 29
are also shown in Figures 26 and 27. The coefficients of determination, $r^2$, were between 0.67 and 0.85 for the sum distribution and between 0.76 and 0.94 for the radial distribution. Therefore, it can be expected that a log-normal distribution would reasonably well fit the data for droplet size in the interval between 5 and 95 percent of the volume sprayed. For these experiments, the log-normal equation was a better fit for the 10 to 90 percent volume range than for the 5 to 95 percent range.

An attempt was made to find a distribution that would better fit the droplet size distributions produced by the rotating disc atomizers under the test conditions. The candidate distribution was the one proposed by Rosin-Rammler in 1933 as quoted from Mugele and Evans (1951) and from Marshall (1954). Later, Weibull (1951) proposed a new function which was a different representation of the Rosin-Rammler distribution. Weibull's equation is best known for its application to reliability predictions. The cumulative volume distributions were plotted using Weibull probability paper and the corresponding parameters were determined from the graphs after adjusting the abscissa axis to account for the value of $\chi$. The $\chi_0$ values were associated with the minimum size of the droplets produced. Determination of additional parameters was accomplished by using
Figure 26. Correlation between dispersion factor $\alpha$ and the geometric standard deviation, $\sigma_{gv}$, for the radial distribution.
Figure 27. Correlation between dispersion factor $\alpha$ and the geometric standard deviation $\sigma_{gv}$ for the sum distribution.
the tables prepared by Mischke (1971).

The Weibull cumulative distribution function is given as

\[ R(X) = \exp\left[-\left(\frac{x-x_0}{\theta}\right)^b\right] \]  

(30)

where

- \( R(X) \) is the reliability function
- \( X \) is the variate
- \( x_0 \) is the guaranteed variate of the Weibull distribution (the minimum value of \( x \))
- \( \theta \) is a Weibull characteristic variate value
- \( b \) is a Weibull shape factor, dimensionless

For particle size distribution the parameters would be renamed as

\[ R(X) = V(d) = \text{cumulative volume value for droplets smaller or equal to } d; \]

\[ x = d = \text{droplet diameter} \]

\[ x_0 = d_0 = \text{minimum guaranteed droplet diameter such that } d_0 > 0 \]

\( \theta \) and \( b \) are two characteristic values associated with the droplet size distribution.

These droplet size distributions were selected at random and the data were plotted using Weibull paper as shown in Figures 28 and 29. The cumulative distribution functions obtained from the data are presented in Table 6, as are the calculated mean, median, mode, standard deviations and
Figure 28. Weibullian distribution for droplet production by disc 4 at 150 Hz and 22 kv. Minimum droplet size, $d_0=15.0$ microns.
Figure 29. Weibullian distribution for droplets produced by disc 3
<table>
<thead>
<tr>
<th>Disc 4 at 150 Hz and +22 kV,</th>
<th>Disc 3 at 50 Hz and OV</th>
<th>Disc 3 at 100 Hz and +22 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d_0 = 15; \ \theta = 135; \ b = 2.80; \ V = \exp[-(\frac{d-15}{135})^{2.80}] )</td>
<td>( d_0 = 18; \ \theta = 350; \ b = 3.85; \ V(d) = \exp[-(\frac{d-18}{350})^{3.85}] )</td>
<td>( d_0 = 18; \ \theta = 230; \ b = 2.98; \ V(d) = \exp[-(\frac{d-18}{230})^{2.98}] )</td>
</tr>
<tr>
<td>Volume mean, ( \mu ) = 135.2 ( \mu m ) (150.0 ( \mu m ))</td>
<td>Volume mean, ( \mu ) = 329.9 ( \mu m ) (357 ( \mu m ))</td>
<td>Volume mean, ( \mu ) = 223.4 ( \mu m ) (229.4 ( \mu m ))</td>
</tr>
<tr>
<td>Standard deviation, ( \sigma ) = 46.5 ( \mu m ) (52.6 ( \mu m ))</td>
<td>Standard deviation, ( \sigma ) = 92.1 ( \mu m ) (94 ( \mu m ))</td>
<td>Standard deviation, ( \sigma ) = 75.1 ( \mu m ) (62.8 ( \mu m ))</td>
</tr>
<tr>
<td>Volume median, ( \tilde{\chi} ) = 133.4 ( \mu m ) (138.6 ( \mu m ))</td>
<td>Volume median, ( \tilde{\chi} ) = 336.3 ( \mu m ) (343.7 ( \mu m ))</td>
<td>Volume median, ( \tilde{\chi} ) = 221.4 ( \mu m ) (218.2 ( \mu m ))</td>
</tr>
<tr>
<td>Pearson's skewness coefficient, ( s ) = 0.106</td>
<td>Pearson's skewness coefficient, ( s ) = -0.077</td>
<td>Pearson's skewness coefficient, ( s ) = 0.064</td>
</tr>
</tbody>
</table>

\(^a\)Note: values between parentheses were computed by the computer program.
Pearson's first coefficient of skewness. In the same table are listed the corresponding values computed through the program shown in Appendix C.

It can be observed in Figures 28 and 29 that data points well-fitted the respective Weibull distribution functions.
VII. SUMMARY

The objectives of this study were to determine the influences of electrostatic potentials applied to rotating disc atomizers for liquid spraying. Two aspects were considered: the electric charging of the spray droplets by contact charging and corona discharge, and the droplet size analysis for the liquid sprayed. A complete factorial experiment with a single replication was used. The tests were run with some fixed variables simulating normal field operations for the laboratory studies.

The contact electrification and corona discharge mechanisms produced appreciable electric charges on the spray droplets of about the same order of magnitude, or even higher, than reported in the literature for charges produced by the induction mechanism. The ratio \( q/m \) calculated from the experimental data was up to 11 percent of the maximum theoretical charge established by the electro-hydrodynamic instability theory. This value is about three times the maximum reported for the inductive charging mechanism.

The effects of potential levels applied to the rotating disc on the mean droplet diameters were not significant for the conditions tested. However, some influence was noticed for the droplets in the lower tail of the drop distribution, although this effect was not consistent. The higher
order interactions were not negligible and a more reliable analysis was not possible. The degree of dispersion of the sprays produced by the rotating discs were in general better than any commercial pressure nozzle. The range in size variation of the droplets produced was a function of the speed and the rotating disc characteristics. The results obtained in this study were comparable with the results from previous authors, even for work done with different discs, feed rates, and liquids.
VIII. CONCLUSIONS

The following conclusions were drawn from this study:

1. Spray droplets can be charged by contact and corona discharge by applying an electric potential to a rotating disc atomizer.

2. Within the potential levels applied, 0 to 22 kV, with both positive and negative polarities, cloud current and therefore the ratio of charge to mass increased exponentially with the potential.

3. The negative polarity at the higher potentials produced larger disc and cloud currents, and therefore produced greater electric charges on the spray droplets.

4. No influence of electric potential on the rotating disc atomizer on the droplet diameter parameters, such as the volume mean diameter, Sauter diameter and surface mean diameter was detectable.

5. Some effects of potential level and its interactions with other factors, speed and disc characteristics, were evident for droplets smaller than 119 microns for some of the statistics, but this was not consistently true.
6. The dispersion coefficient was kept within the range 0.52 to 1.1 for all but one experimental run, had the value 1.56. Potentials applied in the rotating disc atomizer had no effect on dispersion coefficients.

7. A log-normal distribution function provides a reasonably good fit of the droplet size distribution produced by rotating disc atomizers for the range of 10 to 90 percent of the volume cumulative distribution, with and without applied potentials.

8. A Weibull distribution function was a better fit than a log-normal distribution for some of the droplet size distributions obtained experimentally.

9. The water sensitive targets used were satisfactory, but they showed large variations in the spread factor for relative humidities above 80 percent. Care was taken in calibrating the paper, but effects of humidity may not have been completely eliminated.

10. The system used for collecting samples for particle size analysis is accurate, but is not practical for experiments where a large number of droplets are to be counted.
11. Electrostatic disruption of the liquid was not detectable at the flow rates and potentials used, confirming the predominance of the liquid surface tension during the corona charging of water droplets.

12. Charged droplets settled faster than the uncharged ones as indicated by radial pattern distributions. This should improve pesticide deposition on plants.

13. Levels of electric charge imparted per unit mass of the spray encourages future work with higher negative potentials applied on rotating disc atomizers.
IX. BIBLIOGRAPHY


X. ACKNOWLEDGMENTS

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His wife, Vera Lucia, whose encouragement was always present, and children, Roberto and Mirela, for their understanding.
PLEASE NOTE:

Appendices contain computer print-out.
Filmed as received.

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| 1     | 0.40        | 0.55        | 0.50           | 0     | 0   | 2  | 0  | 1  | 0  |    |    |
| 2     | 0.59        | 0.77        | 0.68           | 0     | 0   | 2  | 4  | 2  | 0  |    |    |
| 3     | 0.77        | 0.96        | 0.86           | 2     | 0   | 2  | 7  | 3  | 0  |    |    |
| 4     | 0.56        | 1.14        | 1.05           | 1     | 0   | 2  | 11 | 2  | 1  |    |    |
| 5     | 1.14        | 1.32        | 1.23           | 0     | 0   | 3  | 1  | 13 | 0  |    |    |
| 6     | 1.32        | 1.51        | 1.42           | 0     | 0   | 5  | 3  | 12 | 3  |    |    |
| 7     | 1.51        | 1.60        | 1.60           | 0     | 0   | 2  | 6  | 13 | 2  |    |    |
| 8     | 1.69        | 1.88        | 1.78           | 0     | 3   | 0  | 4  | 23 | 6  |    |    |
| 9     | 1.86        | 2.06        | 1.97           | 0     | 6   | 1  | 7  | 18 | 8  |    |    |
| 10    | 2.06        | 2.24        | 2.15           | 1     | 13  | 0  | 15 | 21 | 7  |    |    |
| 11    | 2.24        | 2.43        | 2.34           | 5     | 31  | 2  | 11 | 9  | 6  |    |    |
| 12    | 2.43        | 2.61        | 2.52           | 3     | 9   | 0  | 20 | 3  | 5  |    |    |
| 13    | 2.61        | 2.80        | 2.70           | 5     | 0   | 0  | 14 | 1  | 2  |    |    |
| 14    | 2.80        | 3.00        | 2.89           | 4     | 1   | 0  | 12 | 2  | 2  |    |    |
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XIII. APPENDIX C. COMPUTER PROGRAM
This program calculates droplet size distribution associated with water sensitive targets for spots measured using a particle size analyzer, Carl Zeiss, Model TG2-3.

The linear scale was used, as well as the reduced range. Pictures were taken at different sampling stations across the radial direction. After enlargement up to 33 times, wherever necessary, spots were counted. The counts were scanned into 48 classes, representing diameters from 0.4 to 9.24 mm. Seven extra classes were created to account for some spots larger than 9.24 mm in diameter, in such a way to have a reasonable enlargement. Spots under such classes were measured by using a common scale with 0.5 mm divisions. The largest class could receive spots up to 11.5 mm in diameter.

The program calculates the equivalent area for the sampled station after considering the enlargement used for the picture, and the characteristic position of the station along the radial direction. The droplet density in the sampled area is corrected by a factor determined by the slit opening.
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DIMENSION DISTL(6), KCLASS(55), KCCUNT(55), ARE(6), FSLIT(6)
DIMENSION NCLASS(6), SLIT(6), SLMA(6), SUMC(6), SUMD(6), SUMS(6)
DIMENSION SUMV(6), DMEAN(6), DVMEAN(6), DMEANV(6), SSD(6), SSV(6)
DIMENSION VARV(6), VARV(6), STDD(6), STDV(6), CV(6), CVV(6)
DIMENSION DAVE(6,55), DSURF(6,55), DAREA(6,55), DVC(6,55)
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DIMENSION CUMV(6,55), NCOUNT(6,55), DLLIM(6,55), DULIM(6,55)
DIMENSION SSA(6), SSS(6), VAR(6)
DIMENSION SAUT(6), SUNV2(6), DVH(6)
DIMENSION XCCUNT(30), XLL(31), XAVE(30)
DIMENSION DIAD(220), RADD(220)
REAL INTL
CCMNMN CCCUNT, DLLIM, DULIM, INTL, CINT, DIAD, RADD
CCMNMN XCCUNT, XLL, XAVE
RL = 67.5
C READ INTERVAL LIMITS AND MEAN VALUES ASSOCIATED WITH, FOR THE
C CLASSES WHERE THE SPOT DIAMETERS WERE SCANNED CN.
READ(5, 101) (INTL(I), I=1,56)
READ(6,101) (CINT(I), I = 1, 55)
101 FORMAT( E(F10.2))
20 PRINT 115
21 115 FORMAT('I'
C READ DATA
C
KMARK = 1
C DC-LOCP TC READ DATA ASSOCIATED WITH EACH OF THE USED SPEEDS
DC 5980 MSP =1, 3
C DC-LOOP TC READ DATA ASSOCIATED WITH EACH ONE OUT THE FIVE POT.
DC 9990 MLV=1,5
C ZERO ALL THE MATRICES BEFORE STARTING A NEW RUN

25 DC 170 J11=1,6
26 ENLG( J11) = 0.0
27 DC 171 J12 = 1, 55
28 CCCUNT( J11,J12) = 0.0
29 DAVE( J11,J12) = 0.0
30 DVCL( J11,J12) = 0.0
31 DSURF( J11,J12) = 0.0
32 DAREA( J11,J12) = 0.0
33 DLLIM( J11,J12) = 0.0
34 DULIM( J11,J12) = 0.0
35 FRACD( J11,J12) = 0.0
36 FRACV( J11,J12) = 0.0
37 CLMD ( J11,J12) = 0.0
38 CUMV ( J11,J12) = 0.0
39 171 NCCUNT( J11, J12) = 0
40 170 CONTINUE
41 J = MLD
42 READ(5,200) NDISC, LIQ, NFL, NSPD, NPCT, NSTNS, CSPEED, FLCE, 1 FCT(J), TCUR, DCUR, CLDCUR, DBT, MBT, RH, SLIT1, SLIT2, DMAX
43 200 FCMAT( 511, 3X, I1, 6(F6.2), 5(F5.2), F8.2)
C
44 PRINT 250, NDISC, LIQ, NFL, NSPD, NPCT, NSTNS, CSPEED, FLCE, PCT(J), 1 TCUR, DCUR, CLDCUR, DBT, MBT, RH, SLIT1, SLIT2, DMAX
45 250 FCMAT( '1', 5(13), 3X, I1,12(F6.2))

C DC-LOCOP TC READ INFORMATION RELATED WITH THE STATION DAMPED
46 CC 299 K1 =1, NSTNS
47 READ( 5,300) N1, N2, N3, N4, N5, N6, NCLASS(K1), ENLG(K1), 1 AREAS(K1), DIST(K1), DISTL(K1)
48 300 FCMAT( 511, 8X, 12, 3X, 12, 3(F10.1),10X,F10.1 )
49 PRINT 350, N1,N2,N3,N4,N5,N6,NCLASS(K1),ENLG(K1),AREAS(K1), 1 DIST(K1),DISTL(K1)
50 350 FCMAT( '*-', 7(15), 4(F10.1),/ )
DC-LOCOP TO READ DATA FOR THE CLASSES SCANNED IN EACH STATION

51 DC 370 JC = 1, 55
52 KCLASS(JC) = 0
53 KCOUNT(JC) = 0
54 370 CONTINUE
55 MAXCL = NCLASS(K1)
56 READ(3,400) (KCLASS(K2),KCOUNT(K2),K2=1,MAXCL)
57 400 FORMAT((EX,10(I2,1X,I3,1X)))

C FILL OUT THE COUNT(NSTNS,NCLASS) MATRIX
C REDUCE DROPLET COUNT TO A REFERENCE AREA, SAY, AREF=10.0 CM².
C AREF = 10.0
C AREF(K1) IS THE AREA SAMPLED IN STATION K1.
C AREAS(K1) IS THE AREA OF THE PICTURE AFTER ENLARGEMENT.
58 AREF(K1) = AREAS(K1)/ENLG(K1)*ENLG(K1)

C CORRECTION ON DROPLET CONCENTRATION DUE TO VARIATION IN SLIT WIDTH. THE RADIAL LENGTH OF THE SLIT IS RL=67.5 CM.
C THE SLIT WIDTH AT THE K1-TH STATION IS
59 SLIT(K1) = SLIT2-((SLIT2-SLIT1)/FL)*DIST(K1)
60 FSLIT(K1) = SLIT(K1)/SLIT(K1)
61
62 DC 399 K2 = 1, MAXCL
63 KK = KCLASS(K2)
64 XLG = ENLG(K1)
65 NCOUNT(K1, KK) = KCOUNT(K2)
66 IF(NCOUNT(K1,KK).EQ.0) GO TO 398
C CALL SLERCUTINE DSIZE.
67 CALL DSIZE(KK,XLG,DAVE1,DLLIM1,DULIM1,DVGL1,DSURF1,DAREA1)
THIS SEGMENT OF MAIN PROGRAM ENSEMBLES THE FOLLOWING MATRICES:
CORRESPONDING TO THE MEAN DROPLET DIAMETER, LOWER AND UPPER
LIMITS OF EACH CLASS, DROPLET MEAN VOLUME, DROPLET MEAN SURFACE,
DROPLET MEAN CROSS-SECTION AREA.

DAVE(K1,KK) = DAVE1
DLLIM(K1,KK) = DLLIM1
DULIM(K1,KK) = DULIM1
DVOL(K1,KK) = DVOL1
DSURF(K1,KK) = DSURF1

A NEW MATRIX FOR COUNT IS CREATED (REAL), CALLED CCOUNT(K1,KK)
WHICH REPRESENTS THE DROPLET CONCENTRATION ON A REFER AREA.
CORRECTION IS ALSO MADE IN TERMS OF SAMPLING TIME CTIME
REPRESENTS THE RATIO OF THE ACTUAL COVER SPEED, CSPEED, BY
A REFERENCE COVER SPEED, REFVEL, FIXED AS 10.0 CM/S, FOR THIS
EXPERIMENT.

REFVEL = 10.0
CTIME = CSPEED/REFVEL
AREA = AREF/ARED(K1)
CCOUNT(K1,KK) = FLOAT(NCOUNT(K1,KK))*CARFA*CTIME*FSLIT(K1)

CONTINUE

CCOUNT

A Inputs for CONFERENCE
PRINT INPUTS FOR CONFERENCE
ALFA = 3000.*FLOAT(NSPD)
WRITE(6,2000) NDISC, ALFA, POT(J),(ENLG(J5),J5=1,6)
2000 FORMAT(IH1,' DISC NO.= ',12,' DISC SPEED= ',F5.0,' RPM',' PCTEN
1TIAL= ', F5.1, ' KV',///,
2 CLASS LOWER UPPER CLASS STA STA STA STA STA STA STA STA STA STA
3 NC. LIMIT LIMIT AVE 1 2 3 4 5 6 */,
4 ENLARGEMENT...*, GAS1, /)
86          KT1 = 0
87          DC 2010 L1=1.55
88          DC 2005 M=1.55TNS
89          2005 KT1 = KT1 + NCOUNT(MN, L1)
90          IF(KT1.GT.0) GC TC 2009
91          WRITE(6,2001) L1, INTL(L1), INTL(L1+1), CINT(L1), (NCOUNT(K1,L1),
1          1 K1=1,NSTNS )
92          2001 FORMAT(1F, 15, 2X, 3F7.2, 6IS )
93          2009 KT1 = 0
94          2010 CONTINUE
95          C
96          EMPT VECTORS BEFORE STATISTICAL CALCULATIONS
97          C
98          DC 6000 J7=1.6
99          SLMA(J7) = 0.0
100         SLMC(J7) = 0.0
101         SLMD(J7) = 0.0
102         SUMS(J7) = 0.0
103         SUMV(J7) = 0.0
104         SUMV2(J7) = 0.0
105         SSA(J7) = 0.0
106         SS1(J7) = 0.0
107         SSV(J7) = 0.0
108         SSJ(J7) = 0.0
109         SSS(J7) = 0.0
110         STDD(J7) = 0.0
111         VAR(J7) = 0.0
112         STDV(J7) = 0.0
113         CV(V(J7) = 0.0
114         CVW(J7) = 0.0
115         DC 6001 J8=1.55
116         CUMMD(J7, J8) = 0.0
117         CUMV(J7, J8) = 0.0
118         6001 CONTINUE
119         6000 CONTINUE
C PREPARE STATISTICS FOR EACH STATION

DC 1010 II=1,NSTNS

DC 1011 KK=1,55

IF( CCOUNT(I1,KK),EQ, 0) GC TC 1012

SUM(I1) = SUMC(I1) + CCOUNT(I1,KK)

SUM(I1) = SUM(I1) + CCOUNT(I1,KK)*DAREA(I1,KK)

SUM(I1) = SUM(I1) + CCOUNT(I1,KK)*DSURF(I1,KK)

SUM(I1) = SUM(I1) + CCOUNT(I1,KK)*DVE(I1,KK)

SUM(I1) = SUM(I1) + CCOUNT(I1,KK)*DVOL(I1,KK)

SUMV2(I1) = SUMV2(I1) + CCOUNT(I1,KK)*DAVE(I1,KK)

SUMC(I1) = SUMC(I1) + SLCM(I1)

SUMV(I1) = SUMV(I1) + SCMV(I1)

C SLN OF SCLARES

SSD(I1) = SSD(I1) + CCOUNT(I1,KK)*DAVE(I1,KK)*2

SSV(I1) = SSV(I1) + CCOUNT(I1,KK)*DVOL(I1,KK)*2

1012 CONTINUE

1011 CONTINUE

1010 CONTINUE

C FRACTION BY NUMBER AND BY VOLUME OF DROPLETS PER CLASS.

DC 1030 II=1,NSTNS

FRACD(I1,1) = CCOUNT(I1,1)/SUM(I1)

FRACV(I1,1) = CCOUNT(I1,1)*DVOL(I1,1)/SUMV(I1)

CLMD(I1,1) = FRACD(I1,1)

CLMV(I1,1) = FRACV(I1,1)

DC 1020 KK=2,55

FRACD(I1,KK) = CCOUNT(I1,KK)/SUMC(I1)

FRACV(I1,KK) = CCOUNT(I1,KK)*DVOL(I1,KK)/SUMV(I1)

CLMD(I1,KK) = CUMMD(I1,KK-1) + FRACD(I1,KK)

CLMV(I1,KK) = CUMV(I1,KK-1) + FRACV(I1,KK)

1020 CONTINUE

1030 CONTINUE

C ARITHMETIC MEANS AND VARIANCES AND STD DEVIATIONS

DC 1500 II=1,NSTNS

DMEAN(I1) = SUMD(I1)/ SUMC(I1)

DMEANV(I1) = SUMV(I1)/SUMC(I1)

DMEANV(I1) = (DVMEAN(I1)*6./3.14159)**0.3333

SALT(I1) = 6.0*SUMV(I1)/SUMS(I1)
C CALCULATE THE HEROAN VOLUME DISTRIBUTION MEAN DIAMETER, DVH

147  DVH(II) = SUMV2(II)/SUMV(II)
148  VARD(II) = (SSD(II) - SUMD(II)*SUMD(II)/SUMC(II))/(SUMC(II) - 1.0)
149  STD(II) = SQRT(VARD(II))
150  VARV(II) = (SSV(II) - SUMV(II)*SUMV(II)/SUMC(II))/(SUMC(II) - 1.0)
151  STDV(II) = SQRT(VARV(II))

C COEFFICIENT OF VARIATION

152  CV(II) = STD(II)/DM(II)
153  CVV(II) = STDV(II)/DVMEAN(II)

154 1500 CONTINUE

C PRINT CLFUT PER STATION. SUPPRESS PRINTING CLASSES WITH NO COUNT

C

155  DC 3100 II = 1, NSTNS

C PRINT READINGS FOR STATION DATA AND STATISTICS.

156  WRITE(6,3100) NDISC, ALFA, PG(MUD), II

157  3009 FORMAT(IH1,* DISC NO. = 'I2,/' D SPEED = ',F5.0,' RPM ',',/ FC

158  TENTIAL = ',F5.1,' KV / STATION NO. = ',I2,,/

159  2 CLASS LOWER UPPER CLASS DROPLET FRACTION FRACTION CUMU

160  ILATIVE CUMULATIVE ',',/

161  4 NO. LIMIT LIMIT DIA.AVE NUMBER DIAMETER VOLUME DIA

162  SMETER VOLUME ',',/

163  DC 3101 KK = I, 55

164  IF(CCOUNT(II,KK).EQ.0.0) GO TO 3200

165  WRITE(6,3110) KK, DLLIM(II,KK), DULIM(II,KK), DAVE(II,KK), CCOUNT(II

166  , KK), FRAC(II,KK), FRACV(II,KK), CUMD(II,KK), CUMV(II,KK)

167  3110 FORMAT(1H1, 15, 3F8.1, F9.3, 4F10.5 )

168  2200 CONTINUE

169  3101 CONTINUE
WRITE(1,3050) DMEAN(II),DVMEAN(II), DMEANV(II), VARO(II),
1 VARV(II),STDD(II), STDV(II), SAUT(II), DVH(II),CVD(II),CVV(II),
2 SUMV(II), SUMC(II)
3050 FORMAT(1HC, 9998, ' STATISTICS PER STATION', 9999)
1' ARITHMETIC MEAN DIAMETER, DMEAN = ...., F10.3, /
1' ARITHMETIC MEAN VOLUME, DVMEAN = ....,E10.3, /
2' MEAN VOLUME DIA.(MUGEL& EVANS)DMEANV = ....,F10.3, /
3' VARIANCE FOR DIAMETER, VARO = ...., F10.3, /
4' VARIANCE FOR VOLUME, VARV = ....,E10.3, /
3' STANDARD DEVIATION FOR DIA., DTDD = ...., F10.3, /
4' STANDARD DEVIATION FOR VOLUME, STDV = ....,E10.3, /
7' SAUTER DIAMETER, SAUT = ...., F10.3, /
7' VOLUME MEAN DIA.(HERFAN), DVH = ...., F10.3, /
5' COEFF OF VARIATION FOR DIA., CVD = ...., F10.3, /
6' COEFF OF VARIATION FOR VOLUME,CVV = ...., F10.3, /
8' TOTAL VOLUME PER REFERENCE AREA = ...., E12.5, /
9' TOTAL NUMBER OF DROPLETS IN REF AREA = ..., F10.3, /
C
3100 CONTINUE
C
DC 3300 NCP=1,2
C
DROPLET SIZE RADIAL DISTRIBUTION
C
CALCULATE STATISTICS FOR THE NEW RADIAL DISTRIBUTION
C
ARITHMETIC MEANS AND RESPECTIVE STANDARD DEVIATIONS CAN BE
CALCULATED FROM PREVIOUS STATIONS DATA.
C
INITIALIZE EMPTY VARIABLES
C

168 TCT0 = 0.0
169 TCT1 = 0.0
170 TCT2 = 0.0
171 TCT3 = 0.0
172 TCT4 = 0.0
173 TCT5 = 0.0
174 TCT6 = 0.0
175 TCT7 = 0.0
176
177 DO 6600 IT = 1,NSTNS
178 CFAC = CI ST(IT)/DIST(1)
179 IF(NOP.EQ.2) CFAC = 1.0
180 TCT0 = TOT0 + SUMC(IT)*CFAC
181 TCT1 = TGT1 + SUMD(IT)*CFAC
182 TCT2 = TOT2 + SUMV(IT)*CFAC
183 TCT3 = TOT3 + SUMA(IT)*CFAC
184 TCT4 = TOT4 + SUM(IT)*CFAC
185 TCT5 = TCT5 + SS D(IT)*CFAC
186 TCT6 = TCT6 + SSV(IT)*CFAC
187 6600 CONTINUE
C SUM OF SQUARES
188 CALCULATE MEANS AND STANDARD DEVIATIONS
189 R D MEAN = TOT1/TOT0
190 RV MEAN = TOT2/TOT0
191 RV VOL = (6.0*RV MEAN/3.14159)**0.3333
192 R AREA = TCT3/TOT0
193 R S A U T = 6.0*TOT2/TOT4
194 R VH = TCT7/TOT2
195 RVARD = (TOT5-TOT1*TOT1/TOT0)/(TCT0 - 1.0)
196 RSTD D = SCRT(RV A R D)
197 RV AR V = (TOT6-TOT2*TOT2/TOT0)/(TCT0 - 1.0)
198 RSTD V = SCRT(RVAR V)
199 RCVD = RSTD /RD MEAN
200 RCVV = RSTDV/RV MEAN
C
C PRINT OUTPUT FOR RADIAL DISTRIBUTION
C
200 WRITE(6, 119)
201 IF(NUP.EQ.2) GO TO 3330
202 WRITE(6,3299):
203 3299 FFORMAT(1H,16,' RADIAL DISTRIBUTION',//)
204 GO TO 3340
205 3330 WRITE(6,3331)
206 3331 FFORMAT(1HC,16,' SUM OF STATIONS DISTRIBUTION',//)
207 3340 WRITE(6,999) NSTNS,TOTO,RMEAN, RVMEAN, RVAL,RSAUT,RAREA,RVH,RSTD,
1 RSTDV,RCVD,RCVV, TCT7
208 999 FFORMAT(1HC,16,
1' NUMBER OF STATIONS SAMPLED, NSTNS=.............', IS,//)
2' TOTAL NUMBER OF DROPLET (SPCTS) IN RUN =........ F10.3,//
3' ARITHMETIC MEAN DIAMETER, BY NUMBER, RMEAN=..... F10.3, //
4' ARITHMETIC MEAN VOLUME, RVMEAN=................ E12.5,//
5' VOLUME MEAN DIAMETER(MUGELE AND EVANS), RMVOL=.. F10.3, //
6' SATUR DIAMETER, RSAUT=......................... F10.3, //
7' ARITHMETIC MEAN CROSS-AREA, RAREA=.............. E12.5, //
8' VOLUME MEAN DIAMETER, RVH (HARDAN)............... F10.3, //
9' DIA. STANDARD DEVIATION, NUMBER, RSTD=......... F10.3, //
10' VOLUME STD DEVIATION, (MUGELE & EVANS), RSTDV=... E12.5, //
1' COEFFICIENT OF VARIATION FOR DIA, RCVD=......., F10.3, //
2' COEFFICIENT OF VARIATION OF VOLUME, RCVV=......... F10.3, //
3' TOTAL VOLUME OF DROPLETS IN RUN=.............. E10.3, //)
C 3350 CONTINUE
C
210 DC 8999 NCP=1,2
C CREATE ARRAY DIAD(M2) REPRESENTING ALL DROPLET SIZE INTERVALS
C FOR THE TOTAL NSTNS IN A RUN. ONLY THE NON-ZERO COUNT INTERVALS
C ARE STORED IN THIS ARRAY. M2 MAX IS SET AT 250.
C A SECOND ARRAY RADD(M2) STANDS FOR RADIAL DISTRIBUTION COUNTING
C TAKING IN ACCOUNT THE CORRECT CONCENTRATION FOR EACH STATION,
C ACCORDING TO ITS POSITION, DIST(I) FROM THE CENTER. THE REFERENCE
C IS THE OUTERMOST STATION, NUMBER 1.
MM2 = 0
DC 76C J8=1,NSTNS
M2 = MM2
DC 790 K2=1.55
IF(COUNT(J8,K8),EQ.0,0) GO TO 750
M2 = M2 + 1
CFAC = DIST(J8)/DIST(1)
IF(NOP,GE.2) CFAC=1.0
DIAD(M2) = DAVE(J8,K3)
RADD(M2) = COUNT(J8,K8)*CFAC
MM2 = M2
750 CONTINUE
750 CONTINUE
CALL SCFT(MM2)

C

GEOMETRIC MEAN ( MEDIAN ) AND GEOMETRIC STANDARD DEVIATION FOR
RACIAL DISTRIBUTION.
C

SGN = 0.0
SGD = 0.0
SSGD = 0.0
SGV = 0.0
SSGV = 0.0
RSVOL = 0.0

C

DISTRIBUTION BY NUMBER
C

DC 785 I =1,MM2
IF(RADD(I),LE.0.0.OR.DIAD(I),LE.0.0 ) GO TO 786
AA = ALGG(DIAD(I))
SGD = SGD + RADD(I)*AA
SSGD = SSGD + RADD(I)*AA*AA
SGN = SGN + RADD(I)
C
C DISTRIBUTION BY VOLUME
AAC = RADD(I)*(DIAD(I)**3)
RSVOL = RSVOL + AAO
SGV = SGV + AAO*AA
SSGV = SSGV + AAO*AA*AA
7E5 CONTINUE
C
C FRACTIONAL CUMMULATIVE RADIAL DISTRIBUTIONS FOR
C AND DROPLET VOLUME
C
K = 1
RFRACJ = RADD(K)/SGN
RFRACV = (RADD(K)*DIAD(K)**3)/RSVOL
RCLMV = RFRACV
RCUMD = RFRACD
IF(NOP.EQ.2) GC TO 777
WRITE(6,7E7)
7E7 FCFORMAT(1H1,/,15X,'RADIAL DISTRIBUTION',//)
GC TO 763
C SUM OF STATIONS DISTRIBUTION
777 WRITE(6,779)
779 FCFORMAT(1H1,/,15X,'SUM OF STATIONS DISTRIBUTION',//)
7E3 CONTINUE
7E3 WRITE(6,78A) K, DIAD(K), RADD(K), RFRACD, RFRACV, RCUMD, RCUMV
WRITE(7,788) K, DIAD(K), RADD(K), RFRACD, RFRACV, RCUMD, RCUMV
788 FCFORMAT(1H1,15X,2F10.2,4F10.5)
DO 789 K = 2,MM2
RFRACD = RADD(K)/SGN
RFRACV = (RADD(K)*DIAD(K)**3)/RSVOL
RCUMD = RCUMD + RFRACD
RCUMV = RCUMV + RFRACV
WRITE(6,78A) K, DIAD(K), RADD(K), RFRACD, RFRACV, RCUMD, RCUMV
WRITE(7,788) K, DIAD(K), RADD(K), RFRACD, RFRACV, RCUMD, RCUMV
C
789 CONTINUE
C
C RADIAL GEOMETRIC MEAN AND STD DEVIATION OF NUMBER DISTRIBUTION
C
266  REX = SGCG/SGN
267  RMD = EXP(REX)
268  S0 = (SGGC - SGD*SGD/SGN)/(SGN -1.)
269  S1 = SORT(S0)
270  RGSTDG = EXP(S1)
C
C RADIAL GEOMETRIC MEAN AND STD DEVIATION OF VOLUME DISTRIBUTION
271  REX = SGV/HSVCL
272  RMV = EXP(REX)
273  S0 = (SGV - SGV*SGV/HSVCL)/RSVCL
274  S1 = SORT(S0)
275  RGSTD = EXP(S1)
276  WHITE(6,751) RMD,RGSTD, RMV, RGSTD
277  751 FORMAT(1HC/, ' RADIAL DISTRIBUTION -- GEOMETRIC MEAN AND STANDA
1RD DEVIATION ',/,
2' GEOMETRIC NUMBER MEAN DIAMETER, RGN=........', F10.3,/,
3' GEOMETRIC STD DEVIATION, NUMBER DISTRIBUTION, RGN=', F10.3,/,
4' GEOMETRIC VOLUME MEAN DIAMETER, RGV=........', F10.3,/,
5' GEOM. STD DEV., VOLUME DISTRIBUTION, RGV=', F10.3,/ )
C
278  8559 CONTINUE
C CALL SUBFCUTINE XCLASS(I1,I2,I3,I4,A1,A2,A3 )
C THIS SUBFCUTINE WILL GENERATE A NEW ARRAY OF THE DROPLETS
C SAMPLED IN ALL STATIONS FOR A SPECIFIC RUN.
C
279  NCP = 2
280  DC 9002 K=1.30
281  XLL(K) = C.0
282  XAVE(K) = 0.0
283  XCCUNT(K) = 0.0
284  9C02 CONTINUE
285  XLL(31) = 0.0
C
CALL XSCALE(2, 25, 10.0, 720.0)

C

DO 9001 I=1,NSTNS
DC 9007 K = 1,30
9007 XCOUNT(K) = 0.0
I4 = I
DISTF = DIST(I)/DIST(I)
IF(NOP.EQ.2) DISTF = 1.0
DC 9011 J = 1,55
M1 = J
IF(COUNT(I,J).EQ.0.0) GO TO 9010
CALL XCLASS(2,M1, 25, 14, 10.0, 720.0, DISTF)
9010 CONTINUE
9011 CONTINUE

KC1 = 1
KC2 = 2
KC3 = 3
KC4 = 4
KC5 = 5
KC6 = 6
WRITE(7,9401) NDISC,LIQ,NSPD,NPOT,I,DIST(I),POT(MUD),ENLG(I),
       1 AWAS(I),DBT,WBT,RH,TCUR,DCUR,CLDCUP,KC1, KMARK
9401 FORMAT(52, 3F6.1, F7.1, 3F5.1, 3F7.3, T75, 12, 14 )
WRITE(7,9402) (XCOUNT(II), II=1,5), KC2, KMARK
9402 FORMAT(7(F10.3, 2X), T75, 12, 14 )
KMARK = KMARK + 1
9001 CONTINUE
C

315      DC 9080 K =1.30
316      XCCUNT(K) = 0.0
317  **3**E0  **C****C**t**E**0 **C**CONT**U**N**E**
318      DC 9024 NCP=1.2
319      DO 9081 I=1,NSTNS
320          I4 = I
321      DISTF = DIST(I)/DIST(1)
322      IF(NOP.EQ.2) DISTF = 1.0
323      DC 9082 J=1.55
324      M1 = J
325      IF(CCCUNT(I,J).EQ.0.0) GO TO 9086
326      CALL XCLASS(2,M1,25,I4,10.0,J, 720.0,DISTF )
327  **3**E0  **C****C**t**E**0 **C**CONT**U**N**E**
328  **3**E2  **C****C**t**E**2 **C**CONT**U**N**E**
329  **3**E1  **C****C**t**E**1 **C**CONT**U**N**E**
330      DC 9209 NR = 1.5
331      NMIN = 1 + 5*(NR -1)
332      NMAX = 5*NR
333      WRITF (7,9210) (XCOUNT(IO) , IO=NMIN,NMAX),NDISC,NSPD,NPCT,NR
334  9210 F**C**R**M**A**T**( 5F12.3, 514)
335  9209 C**C**T**E**N**U**N**E**
C  **C**ALC**U**L**A**TE **S**TA**T**I**S**T**I**C**S **F**O**R** **T**H**E** **N**E**W **D**I**S**T**R**I**B**U**T**I**O**N
336      SRN = 0.0
337      SR1 = 0.0
338      SR2 = 0.0
339      SR3 = 0.0
340      SR4 = 0.0
341      SR5 = 0.0
342      SGND = 0.0
343      SGV = 0.0
344      SSGND = 0.0
345      SSGV = 0.0
C  **A**RITH**E**TIC **D**I**S**T**R**I**B**U**T**I**O**N
346      DC 9500 J =1.25
SRN = SRN + XCOUNT(J)*XAVE(J)
SR1 = SR1 + XCOUNT(J)*XAVE(J)*XAVE(J)
SR2 = SR2 + XCOUNT(J)*XAVE(J)*XAVE(J)**3
SR3 = SR3 + XCOUNT(J)*XAVE(J)*XAVE(J)**4
SR4 = SR4 + XCOUNT(J)*XAVE(J)**5
SR5 = SR5 + XCOUNT(J)*XAVE(J)**5
C GEOMETRIC DISTRIBUTION
A = ALOG(XAVE(J))
SGND = SGND + XCOUNT(J)*A
SSGND = SSNGND + XCOUNT(J)*A*A
SGV = SGV + (XCOUNT(J)*XAVE(J)**3)*A
SSGV = SSGV + (XCOUNT(J)*XAVE(J)**3)*A*A
9500 CONTINUE
C FRACTION DISTRIBUTION BY NUMBER AND BY VOLUME
WRITE(6,6600) NDISC, ALFA, POT(MUD)
9600 FORMAT(1H1,///:
1I3X,
2I3X,DISC NO.,12,/// DISC SPEED=',F5.0,' RPM / POTENTIAL= ',
3 F5.1, ' KV',///,
4I3X,CCLASS CLASS DRCPLET DISTRIBUTION PER RUN',///,
6I3X,NC. AVE.DIA NUMBER NUMBER VOLUME NUMBER VOLUME',
7,/// )
K = 1
RFRACD = XCOUNT(K)*XAVE(K)/SR1
RFRACV = (XCOUNT(K)*XAVE(J)**3)/SR3
RCUMD = RFRACD
RCUMV = RFRACV
WRITE(6,6610) K , XAVE(K), XCOUNT(K), RFRACD, RFRACV, RCUMD, RCUMV
WRITE(7,6630) K, XAVE(K), XCOUNT(K), RFRACD, RFRACV, RCUMD, RCUMV,
1 NDISC, NSPD, NPOT, NDP
9501 K=2,25
RFRACD = XCOUNT(K)*XAVE(K)/SR1
RFRACV = (XCOUNT(K)*XAVE(K)**3)/SR3
RCUMD = RCUMD + RFRACD
RCUMV = RCUMV + RFRACV
C
ARITHMETIC MEAN AND STD DEVIATION
XMEAN  =  SRF1/SRN
XMD = (SRF3/SRN)**0.3333
XS = SRF4/SR3
XSAUT = SRF3/SR2
XMAREA = SQRT( SR2/SRN)
XV = (SR2- SRF1*SRF1/SRN)/(SRN - 1.)
XSTD = SQRT(XV)
XVHD = (SR5 - SRF4*SRF4/SR3)/SR3
XSTDVH = SQRT(XVHD)
XCV = XSTD/XMEAN
XSTDD = SQRT(XV)
XSTDDV = SQRT(XVHD)
XMEAND = XSTD/XMEAN
XMVD = (SRF3/SRN)**0.3333
XS = SRF4/SR3
XSAUT = SRF3/SR2
XMAREA = SQRT( SR2/SRN)
XV = (SR2- SRF1*SRF1/SRN)/(SRN - 1.)
XSTD = SQRT(XV)
XVHD = (SR5 - SRF4*SRF4/SR3)/SR3
XSTDVH = SQRT(XVHD)
XCV = XSTD/XMEAN
XSTDD = SQRT(XV)
XSTDDV = SQRT(XVHD)
WRITE(6,9502) SRN,XMEAN, XMVD, XVHD, XSAUT, XMAREA, XSTDD, XSTDVH,
1 XCV, XSTDDV
9503 CONTINUE

113X, 'TOTAL DROPLET SPOT NUMBER IN A RUN .................', F10.3,
213X, 'NUMBER MEAN DIAMETER( ) ...................................', F10.3,
313X, 'VOLUME MEAN DIAMETER( MUGELE & EVANS ) ............', F10.3,
413X, 'VOLUME MEAN DIAMETER( HERDAN ) .....................', F10.3,
513X, 'SAUTER DIAMETER ......................................', F10.3,
613X, 'AREA MEAN DIAMETER . ...................................', F10.3,
713X, 'STANDARD DEVIATION OF DIAMETER, BY NUMBER ......', F10.3,
813X, 'STANDARD DEVIATION OF VOLUME DIA(HERDAN) ......', F10.3,
913X, 'COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ..', F10.3,
113X, 'COEFF. OF VARI. OF VOLUME MEAN DIAMETER(HERDAN) ..', F10.3,
CONTINUE
C  GECMETRIC DISTRIBUTION
X = SGND/SRN
GMD = EXP(XX)
S0 = (SSGND - SGND*SGND/SRN)/(SRN-1.0)
S1 = SQRT(S0)
GSTDV = EXP(S1)
XX = SGV/SR3
GMV = EXP(XX)
SO = (SSGV - SGV*SGV/SR3)/SR3
S1 = SQRT(SO)
GSTDV = EXP(S1)
WRITE(6,9504) GMD, GMV, GSTDV, GSTDV
9504 FCFMAT(1, /,
11JX, 'GECMETRIC NUMBER MEAN DIAMETER(MEDIAN)..............', F10.3, /,
21JX, 'GECMETRIC VOLUME MEAN DIAMETER(MEDIAN)...............', F10.3, /,
31JX, 'GECMETRIC STANDARD DEVIATION OF NUMBER DIAMETER........', F10.3, /,
41JX, 'GECMETRIC Std DEV OF VOLUME DIAMETER ....................', F10.3, /)
9524 CONTINUE
GO TO 9505
9505 WRITE(6,756) RADD(I), DIAD(I)
756 FCFMAT(1HC, '*** ERRCR MESSAGE *** ', /,
1' DROPLET CONCENTRATION, RADD(I)= ', F10.3, ', OR MEAN DROPLET DIAMETER, DIAD(I)= ', F10.3, '/')
9505 CONTINUE
9550 CONTINUE
9980 CONTINUE
WRITE(6, 119)
STCP
END
***/ SUBROUTINE OSIZE(Il, Al, Bl, D2, 62, 34, 85, 86 ) C A COMMON STATEMENT, FOR INTL AND CINT HAS TO BE PROVIDED IN MAIN C PROGRAM. C SUBROUTINE OSIZE(NN, EN, DAVE1, DLLIM1, DULIM1, DVLOL1, DSURF1, DAREA1 ) COMMON CCCUNT,OLHM,UULIM,INTL,CINT,DIAD,RAAD COMMON XCOUNT, XLL, XAVE C THE DIAMETERS CALCULATED ARE IN MICRONS ( 0,000001 METER ), C ALTHOUGH THE SPOT DIAMETERS ARE GIVEN IN MILLIMETERS. C SAVE1 = 1000. *CINT(NN)/EN SLLIM1 = 1000. *INTL(NN)/EN SULIM1 = 1000. *INTL(NN+1)/EN USE SUBPROGRAM FUNCTION SFACT1 TO CALCULATE THE REAL C DROPLET DIAMETER DAVE1 = SFACT1(SAVE1) DLLIM1 = SFACT1(SLLIM1) DULIM1 = SFACT1(SULIM1) DVLOL1 = 0.5235988*DAVE1**3 DSURF1 = 3.14159*DAVE1*DAVE1 DAREA1 = DSURF1/4.0 RETURN END
**FUNCTION SFACT1(X)**

AA = 1.147
BE = 0.8475
IF (X.LE.0.0) GO TO 3001
IF (X.GE.1.000) GO TO 3005
SFACT1 = AA*X**BE
RETURN

3001 CALL PRINT1(1,X)
SFACT1 = -9999.
RETURN

3005 CALL PRINT1(2,X)
SFACT1 = 9999.
RETURN

END
**THIS SUBROUTINE IS USED TO PRINT ERROR MESSAGES.**

**FOR THE SPOT DIAMETERS OUTSIDE THE SAMPLED RANGE.**

**SUBROUTINE PRINT(K,Y)**

**THIS SUBROUTINE IS USED TO PRINT ERROR MESSAGES.**

**FOR THE SPOT DIAMETERS OUTSIDE THE SAMPLED RANGE.**

```fortran
446        SUBROUTINE PRINT1(K,Y)
447        GC TO ( 4001,4002), K
448      4001 WRITE(6,4003) Y
449      4003 FORMAT('0.*** ERROR MESSAGE ***',
                      ' SPOT DIAMETER = ',E10.2,' IS SMALLER THAN 10 MICRONS',// )
450      RETURN
451      4002 WRITE(6,4004) Y
452      4004 FORMAT('0.*** ERROR MESSAGE ***',
                      ' SPOT DIAMETER EQUALS ',E10.2,' IS LARGER THAN 1800 MICRONS' )
453      RETURN
454      END
```
SUBROUTINE SORT(NT)

DIMENSION DIAD(220), RADD(220), INTL(56), CINT(55)
DIMENSION XCOUNT(30), XLL(31), XAVE(30)
REAL INTL
COMMON XCOUNT, DLLIM, DULIM, MINT, CINT, DIAD, RADD
COMMON XCOUNT, XLL, XAVE
N2 = NT - 1
DC 8000 I=1, N2
N3 = N1 - 1
DC 8120 N1= 1, N3
IF(DIAD(N1) .LE. DIAD(N1+1)) G0 TO 8119
T1 = DIAD(N1)
DIAD(N1) = DIAD(N1+1)
DIAD(N1+1) = T1
T2 = RADD(N1)
RADD(N1) = RADD(N1+1)
RADD(N1+1) = T2

8119 CONTINUE
8120 CONTINUE
8000 CONTINUE
C
RETURN
END
**SUBROUTINE XSCALE( I1, I3, A1, A2 )**

PREPARE ARRAYS XCOUNT(30), XLL(31), XAVE(30)

I1 = 1, EQUALLY SPACED INTERVALS IN REGION (A1, A2)
I1 = 2, GEOMETRIC SCALE WITH CONSTANT GEOMETRIC RATE
I3 = NUMBER OF CLASSES FOR THE NEW SCALE, UP TO 30
A1 = EXTREME LOWER LIMIT FOR THE NEW SCALE
A2 = EXTREME UPPER LIMIT FOR THE NEW SCALE

SUBROUTINE XSCALE( I1, I3, A1, A2 )
DIMENSION COUNT(6, 55), DLLIM(6, 55), DULIM(0, 55)
DIMENSION DIAD(220), RADD(220), INTL(56), CINT(55)
DIMENSION XCOUNT(30), XLL(31), XAVE(30)
REAL INTL
COMMON COUNT, DLLIM, DULIM, INTL, CINT, DIAD, RADD
COMMON XCOUNT, XLL, XAVE

GO TO(7301, 7302), I1

7301 DEL = (A2 - A1)/I3
478 EXL(1) = A1
479 GO TO 7310 J=1, I3
480 XLL(J+1) = XLL(J) + DEL
481 XAVE(J) = (XLL(J+1) + XLL(J))/2.
490 CONTINUE

7310 CONTINUE

RETURN

7362 IF(A1.EQ.0.0.OR.A2.EQ.0.0) GO TO 7396
493 DEL = (A2/A1)**(1./FLGAT(I3))
494 XLL(1) = A1
495 NP = I3 + 1
496 GO TO 7320 J=2+NP
498 XLL(J) = XLL(J-1)*DEL
499 XN = ALOGIC(XLL(J-1)) + ALOG10(DEL)/2.
500 XAVE(J-1) = 10**XN
501 CONTINUE
**SUBROUTINE XCLASS(I1, I2, I3, I4, A1, A2, A3)**

This subroutine takes the count (droplet number) of one of the old J-th intervals and redistribute it on one or more (up to four) of the new classes generated by subroutine XSCALE, which must be run just before calling XCLASS.

The fraction of original count is assigned to the new class according to the fraction that the new class intercepts the old interval. The new array, particle size distribution, is passed back to the main program via a common statement.

I1 is a key. I1=1, the new intervals are equally spaced
I1=2, a geometric scale, with constant geometric rate
I2= actual class, after final reduction to station area
I3= number of classes for the new scale, or array, up to 30.
I4= number of stations
A1= extreme lower limit for the new scale
A2= extreme upper limit for the new scale
A3= scale factor for droplet concentration, CCCUNT(I,J).

A3=1.0 represents simple transposition of data (counts) from old to new classification.
A3 larger than 1.0 means increasing in concentration for the new classification.

Dimensions for A1 and A2 must be in microns.

SUBROUTINE XCLASS(I1, I2, I3, I4, A1, A2, A3)
DIMENSION CCOUNT(6, 55), DLLIM(6, 55), DULIM(6, 55)
DIMENSION DIAD(220), RADD(220), INTL(56), CINT(55)
DIMENSION XCOUNT(30), XLL(31), XAVE(30)
REAL INTL
COMMON CCOUNT, DLLIM, DULIM, INTL, CINT, DIAD, RADD
COMMON XCOUNT, XLL, XAVE

GC TO(7001, 7002), I1

7001 DEL = (A2 - A1) / I3
GC TO 7030

I1 = 2, geometric class intervals, with I3 classes, in (A1, A2)

7002 IF(A1.EQ.0.0 .OR. A2.EQ.0.0) GO TO 7099
DEL = (A2/A1)**(1./FCAT(13))
7010 CONTINUE

GC calculate two pointers, respectively for the lower and upper limit
of the old class interval, I2, which will correspond to the new
class intervals to receive old counts.

KJ1 = IFIX((ALOG10(DLLIM(I4, I2)) - ALOG10(A1)) / ALOG10(DEL)) + 1
KJ2 = IFIX((ALOG10(DULIM(I4, I2)) - ALOG10(A1)) / ALOG10(DEL)) + 1
NDIF = KJ2 - KJ1 + 1
DIFCL = DULIM(I4, I2) - DLLIM(I4, I2)
GG TO (7201, 7202, 7203, 7204), NDIF
7201 XCOUNT(KJ1) = XCOUNT(KJ1) + CCOUNT(I4, I2)*A3
RETURN
C DETERMINE FRACTION OF THE OLD INTERVAL INTERCEPTING TWO OF THE NEW INTERVALS.

527   72(2) FD1 = (XLL(KJ1+1) - DLLIM(I4, I2))/DIFCL
528
529   FD2 = 1. - FD1
530   XCOUNT(KJ1) = XCOUNT(KJ1) + FD1*CCOUNT(I4, I2)*A3
531   XCOUNT(KJ1+1) = XCOUNT(KJ1+1) + FD2*CCOUNT(I4, I2)*A3
532   RETURN

C OLD INTERVAL COVERS THREE OF THE NEW INTERVALS

533   72(3) FD1 = (XLL(KJ1+1) - DLLIM(I4, I2))/DIFCL
534
535   FD2 = (XLL(KJ1+2) - XLL(KJ1 +1))/ DIFCL
536   FD3 = 1. - FD1 - FD2
537   XCOUNT(KJ1) = XCOUNT(KJ1) + FD1*CCOUNT(I4, I2)*A3
538   XCOUNT(KJ1+1) = XCOUNT(KJ1+1) + FD2*CCOUNT(I4, I2)*A3
539   XCOUNT(KJ1+2) = XCOUNT(KJ1+2) + FD3*CCOUNT(I4, I2)*A3
540   RETURN

C OLD INTERVAL COVERS FIVE OF THE NEW INTERVALS.

541   72(4) FD1 = (XLL(KJ1+1) - DLLIM(I4, I2))/DIFCL
542
543   FD2 = (XLL(KJ1+2) - XLL(KJ1+1))/ DIFCL
544   FD3 = (XLL(KJ1+3) - XLL(KJ1+2))/ DIFCL
545   FD4 = 1. - FD1 - FD2 - FD3
546   XCOUNT(KJ1) = XCOUNT(KJ1) + FD1*CCOUNT(I4, I2)*A3
547   XCOUNT(KJ1+1) = XCOUNT(KJ1+1) + FD2*CCOUNT(I4, I2)*A3
548   XCOUNT(KJ1+2) = XCOUNT(KJ1+2) + FD3*CCOUNT(I4, I2)*A3
549   XCOUNT(KJ1+3) = XCOUNT(KJ1+3) + FD4*CCOUNT(I4, I2)*A3
550   RETURN

C PROTECTION AND ERROR MESSAGE

551   7059 WRITE(6,7058) A1, A2
552   7058 FORMAT(1HC, ' *** ERROR MESSAGE ***',//,
553           1 ' LOWER LIMIT, A1= ', E10.2, ' CR, UPPER LIMIT, A2= ', E10.2, '/,
554           2 ' HAS A ZERO VALUE ',// )
555
556   RETURN
557   END
XIV. APPENDIX D. DROPLET SIZE DISTRIBUTION BY STATION
(EXAMPLES SELECTED AT RANDOM)
**DISC NO.** = 2 / **D SPEED** = 6000 RPM / **POTENTIAL** = -8.0 KV / **STATION NO.** = 1

<table>
<thead>
<tr>
<th>CLASS NO.</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
<th>DROPLET FRACTION</th>
<th>CLASS FRACTION</th>
<th>CUMULATIVE DIAMETER</th>
<th>CUMULATIVE VOLUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>195.4</td>
<td>206.2</td>
<td>2.549</td>
<td>0.0506</td>
<td>0.0299</td>
<td>0.0506</td>
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<tr>
<td>15</td>
<td>206.2</td>
<td>217.0</td>
<td>6.374</td>
<td>0.1250</td>
<td>0.0877</td>
<td>0.1727</td>
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<tr>
<td>16</td>
<td>217.0</td>
<td>228.3</td>
<td>12.747</td>
<td>0.2500</td>
<td>0.2051</td>
<td>0.4251</td>
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<tr>
<td>17</td>
<td>228.3</td>
<td>238.9</td>
<td>10.198</td>
<td>0.2000</td>
<td>0.1887</td>
<td>0.6250</td>
</tr>
<tr>
<td>18</td>
<td>238.9</td>
<td>250.0</td>
<td>10.198</td>
<td>0.2000</td>
<td>0.1887</td>
<td>0.6250</td>
</tr>
<tr>
<td>19</td>
<td>250.0</td>
<td>266.4</td>
<td>3.324</td>
<td>0.0750</td>
<td>0.0923</td>
<td>0.5000</td>
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<tr>
<td>20</td>
<td>266.4</td>
<td>286.9</td>
<td>1.275</td>
<td>0.0250</td>
<td>0.0391</td>
<td>0.6250</td>
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<tr>
<td>21</td>
<td>286.9</td>
<td>307.9</td>
<td>1.275</td>
<td>0.0250</td>
<td>0.0391</td>
<td>0.6250</td>
</tr>
</tbody>
</table>

**STATISTICS PER STATION**

- **ARITHMETIC MEAN DIAMETER, DMEAN** = 235.660
- **ARITHMETIC MEAN VOLUME, DMMEAN** = 0.707E -07
- **MEAN VOLUME DIAMETER (MUECLE & EVANS), DMMEAN** = 235.660
- **VARIANCE FOR DIAMETER, VARD** = 531.324
- **VARIANCE FOR VOLUME, VAVR** = 0.524E -13
- **STANDARD DEVIATION FOR DIAMETER, STDSD** = 23.051
- **STANDARD DEVIATION FOR VOLUME, STDV** = 0.229E -07
- **SAUTER DIAMETER, SAUT** = 240.483
- **VOLUME MEAN DIAMETER (HERCANT), DVH** = 243.114
- **COEFF OF VARIATION FOR DIAMETER, CVI** = 0.098
- **COEFF OF VARIATION FOR VOLUME, CVI** = 0.324
- **TOTAL VOLUME PER REFERENCE AREA** = 0.36052E 09
- **TOTAL NUMBER OF DROPLETS IN REF AREA** = 50.990
<table>
<thead>
<tr>
<th>CLASS NO.</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
<th>DIA. AVE NUMBER</th>
<th>FRACTION DIAMETER</th>
<th>FRACTION VOLUME</th>
<th>CUMULATIVE DIAMETER</th>
<th>CUMULATIVE VOLUME</th>
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<tr>
<td>3</td>
<td>34.5</td>
<td>42.3</td>
<td>38.5</td>
<td>4.052</td>
<td>0.01961</td>
<td>0.00189</td>
<td>0.01961</td>
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<td>0.00718</td>
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<td>7</td>
<td>62.7</td>
<td>69.1</td>
<td>65.9</td>
<td>16.207</td>
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<td>0.03794</td>
<td>0.26588</td>
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<tr>
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<td>69.1</td>
<td>75.8</td>
<td>72.3</td>
<td>28.362</td>
<td>0.13725</td>
<td>0.08763</td>
<td>0.34314</td>
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<td>75.8</td>
<td>82.1</td>
<td>78.9</td>
<td>32.414</td>
<td>0.15686</td>
<td>0.13040</td>
<td>0.50000</td>
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<td>88.2</td>
<td>85.2</td>
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<td>0.22512</td>
<td>0.71565</td>
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<tr>
<td>11</td>
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<td>94.7</td>
<td>91.6</td>
<td>26.336</td>
<td>0.12745</td>
<td>0.16582</td>
<td>0.84314</td>
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<tr>
<td>12</td>
<td>94.7</td>
<td>100.7</td>
<td>97.7</td>
<td>16.207</td>
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<tr>
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<td>106.1</td>
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<tr>
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<tr>
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<td>145.6</td>
<td>2.026</td>
<td>0.00980</td>
<td>0.03515</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

**STATISTICS PER STATION**

<p>| Arithmetic Mean Diameter, D MEAN = ...... | 60.311 |
| Arithmetic Mean Volume, D V MEAN = ...... | 0.310E 06 |
| Mean Volume Dia. (Mugele &amp; Evans) D MEAN = | 83.909 |
| Variance for Diameter, VAR D = ........... | 302.928 |
| Variance for Volume, VAR V = ............ | 0.456E 11 |
| Standard Deviation for Diameter, DTDD = .... | 17.405 |
| Standard Deviation for Volume, STDV = ... | 0.214E 06 |
| Sauter Diameter, S A U T = ............... | 87.622 |
| Volume Mean Dia. (Herican) D VH = ........ | 51.302 |
| Coeff of Variation for Diameter, CV D = ... | 0.217 |
| Coeff of Variation for Volume, CV V = .... | 0.089 |
| Total Volume per Reference Area = ........ | 0.64004E 08 |
| Total Number of Droplets in Ref Area = ... | 206.636 |</p>
<table>
<thead>
<tr>
<th>CLASS NO.</th>
<th>LOWER LIMIT</th>
<th>UPPER LIMIT</th>
<th>CLASS DROPLET NUMBER</th>
<th>MEAN DIAMETER</th>
<th>MEAN VOLUME</th>
<th>VOLUME CUMULATIVE DIAMETER</th>
<th>VOLUME CUMULATIVE VOLUME</th>
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<tbody>
<tr>
<td>3</td>
<td>27.2</td>
<td>33.0</td>
<td>30.0</td>
<td>11.7</td>
<td>0.02455</td>
<td>0.00336</td>
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<td>33.0</td>
<td>38.3</td>
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<td>27.4</td>
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<td>0.01315</td>
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STATISTICS PER STATION

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| ARITHMETIC MEAN VOLUME, DVMEN = | 0.103E 06 |
| MEAN VOLUME DIAMETER (McCLELLENS) DMEAN = | 55.140 |
| VARIANCE FOR DIAMETER, VARD = | 55.140 |
| VARIANCE FOR VOLUME, VARV = | 0.785E 10 |
| STANDARD DEVIATION FOR DIA, DTDD = | 12.639 |
| STANDARD DEVIATION FOR VOLUME, STDV = | 0.888E 05 |
| SAULTER DIAMETER, SALT = | 61.332 |
| VOLUME MEAN DIAMETER HERCASON, DVM = | 65.156 |
| COEFFICIENT OF VARIATION FOR DIA, CV = | 0.229 |
| COEFFICIENT OF VARIATION FOR VOLUME, CVV = | 0.862 |
| TOTAL VOLUME PER REFERENCE AREA = | 492.09E 08 |
| TOTAL NUMBER OF DROPLETS IN REF AREA = | 477.632 |</p>
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**STATISTICS PER STATION**

- Arithmetic Mean Diameter, $D_{mean} = 221.595$
- Arithmetic Mean Volume, $D_{vmean} = 0.691E-07$
- Mean Volume Diameter, $D_{meanv} = 236.235$
- Variance for Diameter, $Var_{d} = 4511.875$
- Variance for Volume, $Var_{v} = 0.100E-14$
- Standard Deviation for Diameter, $Stdev_{d} = 67.170$
- Standard Deviation for Volume, $Stdev_{v} = 0.316E-07$
- Sauter Diameter, $S_{at} = 247.023$
- Volume Mean Diameter, $D_{vmean} = 249.573$
- Coefficient of Variation for Diameter, $C_{vd} = 0.303$
- Coefficient of Variation for Volume, $C_{vv} = 0.458$
- Total Volume per Reference Area, $V_{ref} = 0.19629E-09$
- Total Number of Droplets in Reference Area, $N_{ref} = 28.389$
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**Statistics per Station**

- **Arithmetic Mean Diameter, Dmean**: 97.298
- **Arithmetic Mean Volume, Dmean**: 0.555E 06
- **Mean Volume Class**: (Mean = 164.330)
- **Variance for Diameter, VarD**: 855.003
- **Variance for Volume, VarV**: 0.122E 12
- **Standard Deviation for Diameter, StdD**: 29.240
- **Standard Deviation for Volume, StdV**: 0.349E 06
- **Salter Diameter, SalD**: 110.219
- **Volume Mean Diameter, Dvh**: 112.891
- **Coefficient of Variation for Diameter, CvD**: 0.301
- **Coefficient of Variation for Volume, CvV**: 0.587
- **Total Volume Pfr Reference Area**: 0.11366E 09
- **Total Number of Droplets in Ref Area**: 150.895
XV. APPENDIX E. SUM DISTRIBUTION BY RUN
### Droplet Distribution per Run

**Disc No. 2 / Disc Speed: 3000. RPM / Potential: 0.0 KV**

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### Statistics per Run

- **Total Drip: Spot Number in a Run**: 211,299
- **Number Mean Diameter (Mugie & Evans)**: 178.525
- **Volume Mean Diameter**: 236.204
- **Volume Mean Diameter (Herdan)**: 358.579
- **Sauter Diameter**: 304.961
- **Area Mean Diameter**: 208.049
- **Standard Deviation of Diameter, by Number**: 107.087
- **Standard Deviation of Volume Diameter (Herdan)**: 124.513
- **Coefficient of Variation of Diameter (Number)**: 0.600
- **Coefficient of Variation of Volume Diameter (Herdan)**: 0.347

**Geometric**
- **Number Mean Diameter (Median)**: 149.766
- **Volume Mean Diameter (Median)**: 333.809
- **Geometric Standard Deviation of Number Diameter**: 1.837
- **Geometric Standard Deviation of Volume Diameter**: 1.492
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=3000 RPM / POTENTIAL=-8.0 KV**

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**Note:** The class values range from 0.06 to 0.56, with the cumulative volume percentage increasing from 0.07 to 1.00.
DROPLET DISTRIBUTION PER RUN

DISC NO. 2 / DISC SPEED=3000. RPM / POTENTIAL=-22.0 KV

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STATISTICS PER RUN

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VOLUME MEAN DIAMETER( HERDAN )................................ 356.223
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GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN)....................... 334.896
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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 382.307
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- **VOLUME MEAN DIAMETER (HERDAN)**: 321.373
- **SALTER DIAMETER**: 285.438
- **AREA MEAN DIAMETER**: 198.575
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 104.704
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)**: 91.453
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.620
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.285

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 137.875
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 305.761
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.932
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.404
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### Statistics Per Run

- Total droplet spec number in a run: 531,706
- Number mean diameter: 150.453
- Volume mean diameter (Mugele & Evans): 187.434
- Volume mean diameter (Herdan): 252.659
- Sauter diameter: 227.563
- Area mean diameter: 170.241
- Standard deviation of diameter, by number: 79.736
- Standard deviation of volume diameter (Herdan): 66.977
- Coefficient of variation of diameter (number): 0.530
- Coeff. of var. of volume mean diameter (Herdan): 0.265
- Geometric number mean diameter (median): 129.753
- Geometric volume mean diameter (median): 241.716
- Geometric standard deviation of number diameter: 1.752
- Geometric std dev of volume diameter: 1.377
### Droplet Distribution per Run

**Disc No. 2 / Disc Speed=6000 RPM / Potential= -8.0 KV**

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**Statistics per Run**

- Total Droplet Spot Number in a Run: 761,198
- Number Mean Diameter: 109.373
- Volume Mean Diameter (Mugele & Evans): 132.880
- Volume Mean Diameter (Herdan): 182.523
- Salter Diameter: 139.619
- Area Mean Diameter: 121.329
- Standard Deviation of Diameter, by Number: 52.564
- Standard Deviation of Volume Diameter (Herdan): 59.973
- Coefficient of Variation of Diameter (Number): 0.480
- Coeff. of Var. of Volume Mean Diameter (Herdan): 0.329

- Geometric Number Mean Diameter (Median): 97.494
- Geometric Volume Mean Diameter (Median): 171.675
- Geometric Standard Deviation of Number Diameter: 1.632
- Geometric Std. Dev. of Volume Diameter: 1.441
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=6000 RPM / POTENTIAL= 8.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 943,350
- **NUMBER MEAN DIAMETER**: 110.329
- **VOLUME MEAN DIAMETER (MUGLE & EVANS)**: 132.447
- **VOLUME MEAN DIAMETER (HERDAN)**: 175.878
- **SAUTER DIAMETER**: 150.672
- **AREA MEAN DIAMETER**: 121.867
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 51.809
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)**: 53.755
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.300
- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 98.123
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 166.847
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.653
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.403
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=6000 RPM / POTENTIAL=-22.0 KV**

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### STATISTICS PER RUN

- Total droplet spot number in a run: 951.348
- Number mean diameter (Mugele & Evans): 100.637
- Volume mean diameter (Mugele & Evans): 129.250
- Sauter diameter (Herdan): 186.726
- Area mean diameter: 162.460
- Standard deviation of number diameter: 56.440
- Standard deviation of volume diameter (Herdan): 58.371
- Coefficient of variation of diameter (number): 0.561
- Coeff. of var. of volume mean diameter (Herdan): 0.313

- Geometric number mean diameter (median): 86.666
- Geometric volume mean diameter (median): 175.822
- Geometric standard deviation of number diameter: 1.728
- Geometric std dev of volume diameter: 1.448
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=6000 RPM / POTENTIAL= 22.0 KV**

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**STATISTICS PER RUN**

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| Geometric Number Mean Diameter(Median) | 97.813 |
| Geometric Volume Mean Diameter(Median) | 192.786 |
| Geometric Standard Deviation of Number Diameter | 1.693 |
| Geometric Std Dev of Volume Diameter | 1.460 |
## DROPLET DISTRIBUTION PER RUN

**CISC NO. 2 / DISC SPEED=9000 RPM / POTENTIAL= 0.0 KV**

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### STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 1440.138
- **NUMBER MEAN DIAMETER**: 94.707
- **VOLUME MEAN DIAMETER**: 111.542
- **VOLUME MEAN DIAMETER**: 138.877
- **SAUTER DIAMETER**: 128.574
- **AREA MEAN DIAMETER**: 103.966
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 42.727
- **STANDARD DEVIATION OF VOLUME DIAMETER**: 32.119
- **COEFFICIENT OF VARIATION OF DIAMETER**: 0.451
- **CUEFF. OF VAR. OF VOLUME MEAN DIAMETER**: 0.231
- **ECMCETRIC NUMBER MEAN DIAMETER**: 84.333
- **ECMCETRIC VOLUME MEAN DIAMETER**: 134.346
- **ECMCETRIC STC DEV OF NUMBER DIAMETER**: 1.659
- **ECMCETRIC STC DEV OF VOLUME DIAMETER**: 1.316
### Droplet Distribution Per Run

**Class Distribution**

**Class No. 2** / **Disc Speed = 9000 RPM** / **Potential = -8.0 KV**

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**Statistics Per Run**

- **Total Droplet Spot Number in a Run**: 998.040
- **Number Mean Diameter**: 92.591
- **Volume Mean Diameter (Mugele & Evans)**: 107.770
- **Volume Mean Diameter (Herdan)**: 138.310
- **Sauter Mean Diameter**: 124.412
- **Area Mean Diameter**: 100.374
- **Standard Deviation of Diameter, by Number**: 38.773
- **Standard Deviation of Volume Diameter (Herdan)**: 40.478
- **Coefficient of Variation of Diameter (Number)**: 0.412
- **Coefficient of Variation of Volume Diameter (Herdan)**: 0.293

- **Geometric Number Mean Diameter (Median)**: 84.705
- **Geometric Volume Mean Diameter (Median)**: 131.763
- **Geometric Standard Deviation of Number Diameter**: 1.539
- **Geometric Standard Deviation of Volume Diameter**: 1.385
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=9000. RPM / POTENTIAL= 8.0 KV**

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### STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 1682.791
- **NUMBER MEAN DIAMETER**: 105.329
- **VOLUME MEAN DIAMETER (MUGGLE & EVANS)**: 129.035
- **VOLUME MEAN DIAMETER (HERDAN)**: 173.891
- **SALTER DIAMETER**: 154.981
- **AREA MEAN DIAMETER**: 117.825
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 52.821
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)**: 52.005
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.501
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.299

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 92.277
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 165.182
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.698
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.401
## Droplet Distribution Per Run

**Disc No. 2 / Disc Speed = 9000 RPM / Potential = -22.0 KV**

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### Statistics Per Run

- **Total Droplet Spot Number in a Run**: 1606.157
- **Number Mean Diameter**: 68.674
- **Volume Mean Diameter (Mugele & Evans)**: 45.137
- **Volume Mean Diameter (Herdan)**: 147.120
- **Area Mean Diameter**: 127.760
- **Standard Deviation of Diameter, by Number**: 45.101
- **Standard Deviation of Volume Diameter (Herdan)**: 40.196
- **Coefficient of Variation of Diameter (Number)**: 0.657
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.273

- Geometric Number Mean Diameter (Median): 57.617
- Geometric Volume Mean Diameter (Median): 139.334
- Geometric Standard Deviation of Number Diameter: 1.760
- Geometric Standard Deviation of Volume Diameter: 1.445
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=9000 RPM / POTENTIAL= 22.0 KV**

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**STATISTICS PER RUN**

| TOTAL DROPLET SPOT NUMBER IN A RUN | 176.772 |
| NUMBER MEAN DIAMETER | 201.986 |
| VOLUME MEAN DIAMETER | 263.292 |
| VOLUME MEAN DIAMETER | 357.955 |
| SAUTER DIAMETER | 325.794 |
| AREA MEAN DIAMETER | 236.891 |
| STANDARD DEVIATION OF DIAMETER | 124.121 |
| STANDARD DEVIATION OF VOLUME DIA | 94.828 |
| COEFFICIENT OF VARIATION OF DIAMETER | 0.615 |
| COEFF. OF VAR. OF VOLUME MEAN DIAMETER | 0.265 |
| GEOMETRIC NUMBER MEAN DIAMETER | 157.836 |
| GEOMETRIC VOLUME MEAN DIAMETER | 343.678 |
| GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER | 2.167 |
| GEOMETRIC STD DEV OF VOLUME DIAMETER | 1.353 |
### DROPLET DISTRIBUTION PER RUN

**DISC No. 3 / DISC SPEED=3000. RPM / POTENTIAL= -8.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 271.821
- **NUMBER MEAN DIAMETER**: 176.536
- **VOLUME MEAN DIAMETER**: 260.292
- **VOLUME MEAN DIAMETER**: 260.292
- **VOLUME MEAN DIAMETER**: 260.292
- **SAUER DIAMETER**: 379.889
- **AREA MEAN DIAMETER**: 346.605
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 140.971
- **STANDARD DEVIATION OF VOLUME DIA(HERDAN)**: 97.382
- **COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)**: 0.799
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN)**: 0.256

- **GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN)**: 116.621
- **GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN)**: 365.445
- **GECM. STANDARD DEVIATION OF NUMBER DIAMETER**: 2.671
- **GECM. STANDARD DEVIATION OF VOLUME DIAMETER**: 1.345
DROPLET DISTRIBUTION PER RUN  
CISC NO. 3 / DISC SPEED=3000. RPM / POTENTIAL= 8.0 KV

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STATISTICS PER RUN

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VOLUME MEAN DIAMETER( MUGне & EVANS ) .............. 241.124
VOLUME MEAN DIAMETER( HERDAN ) ........................ 378.194
SAUTER DIAMETER .......................................... 340.973
AREA MEAN DIAMETER ...................................... 202.936
STANDARD DEVIATION OF DIAMETER, BY NUMBER .......... 133.782
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN) ....... 92.998
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ...... 0.876
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ..... 0.246

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ............ 100.918
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ............. 363.206
GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER .... 2.565
GEOMETRIC STD DEV OF VOLUME DIAMETER ............... 1.367
DROPLET DISTRIBUTION PER RUN
CISC NO. 3 / DISC SPEED=3000. RPM / POTENTIAL=-22.0 KV

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VOLUME MEAN DIAMETER ( HEROAN ) .............................. 305.807
SAUTER DIAMETER .................................................. 274.708
AREA MEAN DIAMETER .............................................. 193.504
STANDARD DEVIATION OF DIAMETER, BY NUMBER ................. 101.309
STANDARD DEVIATION OF VOLUME DIA(HERDAN) .................. 78.132
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ............ 0.614
COEFF. OF VARI. OF VOLUME MEAN DIAMETER(HERDAN) .......... 0.255

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) .................... 134.263
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ..................... 292.742
GEOM. STANDARD DEVIATION OF NUMBER DIAMETER .......... 1.959
GEOMETRIC STD DEV OF VOLUME DIAMETER ..................... 1.380
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DISC NO. 3 / DISC SPEED=3000. RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN
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VOLUME MEAN DIAMETER( HERDAN ) ....................... 293.417
SAUTER DIAMETER ....................................... 255.177
AREA MEAN DIAMETER .................................... 180.471
STANDARD DEVIATION OF DIAMETER, BY NUMBER .......... 88.793
STANDARD DEVIATION OF VOLUME DIAMETRHERDAN) ....... 90.618
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ...... 0.565
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ... 0.309

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ............. 134.518
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ............. 276.378
GEOM. STANARD DEVIATION OF NUMBER DIAMETER ...... 1.769
GEOMETRIC STD DEV OF VOLUME DIAMETER ............... 1.449
## DROPLET DISTRIBUTION PER RUN

**CISC NO. 3 / DISC SPEED=6000 RPM / POTENTIAL= 0.0 KV**

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## STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 834.243
- **NUMBER MEAN DIAMETER**: 114.184
- **VOLUME MEAN DIAMETER (MUGEL & EVANS)**: 155.613
- **VOLUME MEAN DIAMETER (HERDAN)**: 229.417
- **SAUTER DIAMETER**: 202.829
- **AREA MEAN DIAMETER**: 136.405
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 74.667
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)**: 62.778
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.654
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.274

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 91.623
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 218.232
- **GEOM. STANDARD DEVIATION OF NUMBER DIAMETER**: 1.981
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.413
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### STATISTICS PER RUN

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- **VOLUME MEAN DIAMETER** (HERDAN): 172.877
- **VOLUME MEAN DIAMETER** (HERDAN): 278.540
- **SALTER DIAMETER**: 232.959
- **AREA MEAN DIAMETER**: 149.039
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 81.742
- **STANDARD DEVIATION OF VOLUME DIA(HERDAN)**: 98.249
- **COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)**: 0.656
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN)**: 0.353

- **GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN)**: 102.630
- **GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN)**: 257.978
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.864
- **GEOMETRIC STO DEV OF VOLUME DIAMETER**: 1.521
DROPLET DISTRIBUTION PER RUN
DISC NO. 3 / DISC SPEED=6000 RPM / POTENTIAL= 8.0 KV

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VOLUME MEAN DIAMETER( HERDAN ) ............................ 277.668
SAUTER DIAMETER ............................................ 243.044
AREA MEAN DIAMETER ......................................... 163.330
STANDARD DEVIATION OF DIAMETER, BY NUMBER .............. 89.895
STANDARD DEVIATION OF VOLUME DIAM(HERDAN) ............... 80.926
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) .......... 0.659
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ....... 0.291

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ................. 106.445
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) .................. 262.616
GEOMETRIC STD DEV OF NUMBER DIAMETER .......... 2.132
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DROPLET DISTRIBUTION PER RUN

DISC NO. 3 / DISC SPEED=6000 RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN

TOTAL DROPLET SPOT NUMBER IN A RUN .................. 1172.948
NUMBER MEAN DIAMETER( ) ................................ 106.464
VOLUME MEAN DIAMETER( MUGELE & EVANS ) .............. 161.492
VOLUME MEAN DIAMETER( HERDAN ) ........................ 289.662
SAUTER DIAMETER ........................................ 237.597
AREA MEAN DIAMETER ...................................... 133.241
STANDARD DEVIATION OF DIAMETER, BY NUMBER .......... 80.151
STANDARD DEVIATION OF VOLUME DIA(HERDAN) .......... 92.612
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ...... 0.753
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) .... 0.320

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) .............. 85.456
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) .............. 268.444
GEOM. STANDARD DEVIATION OF NUMBER DIAMETER ...... 1.914
GEOMETRIC STD DEV OF VOLUME DIAMETER ............... 1.549
### Droplet Distribution per Run

**CISC No. 3 / Disc Speed = 9000 RPM / Potential = 0.0 KV**

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### DROPLET DISTRIBUTION PER RUN

**CISC NO. 3 / DISC SPEED=9000 RPM / POTENTIAL= -8.0 KV**

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### STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN** .......... 1716,311
- **NUMBER MEAN DIAMETER** .................................. 105.520
- **VOLUME MEAN DIAMETER (NUGGELE & EVANS)** .......... 124.363
- **VOLUME MEAN DIAMETER (HERDAN)** ..................... 156.468
- **SAUTER DIAMETER** ........................................ 143.824
- **AREA MEAN DIAMETER** ..................................... 115.727
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER** ...... 47.535
- **STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN)** .. 38.544
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)** .. 0.450
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)** .. 0.246

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)** ........ 93.921
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)** .......... 150.815
- **GEOM. STANDARD DEVIATION OF NUMBER DIAMETER** .... 1.663
- **GEOMETRIC STD DEV OF VOLUME DIAMETER** ............ 1.334
DROPLET DISTRIBUTION PER RUN
CISC NO. 3 / DISC SPEED=9000. RPM / POTENTIAL= 8.0 KV

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VOLUME MEAN DIAMETER( HERDAN )................................ 173.013
SAUTER DIAMETER .................................................. 156.026
AREA MEAN DIAMETER ............................................... 121.626
STANDARD DEVIATION OF DIAMETER, BY NUMBER.................... 53.028
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN)................ 50.712
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)................. 0.484
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN)................ 0.293

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN)......................... 95.794
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN)........................ 165.089
GEOM. STANDARD DEVIATION OF NUMBER DIAMETER ................. 1.723
GEOMETRIC STD DEV OF VOLUME DIAMETER ......................... 1.376
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### STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 3083406
- **NUMBER MEAN DIAMETER**: 79.489
- **VOLUME MEAN DIAMETER (MUGLE & EVANS)**: 108.770
- **VOLUME MEAN DIAMETER (HERDAN)**: 167.404
- **SAUTER DIAMETER**: 143.363
- **AREA MEAN DIAMETER**: 94.809
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 51.683
- **STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN)**: 56.228
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.650
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.336

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 64.452
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 156.517
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.477
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.935
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DISC NO. 3 / DISC SPEED=9000 RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN
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VOLUME MEAN DIAMETER( MUGE & EVANS ) ............... 119.047
VOLUME MEAN DIAMETER( HERDAN ) ....................... 167.182
SAUTER DIAMETER ........................................ 148.077
AREA MEAN DIAMETER .................................... 106.818
STANDARD DEVIATION OF DIAMETER, BY NUMBER......... 53.869
STANDARD DEVIATION OF VOLUME DIA(HERDAN) .......... 49.515
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ..... 0.584
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) .. 0.296

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ............. 74.757
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ............. 158.525
GECM. STANARD DEVIATION OF NUMBER DIAMETER ....... 2.033
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**STATISTICS PER RUN**

- **Total DROPLET Spot Number in a Run**: 2154.041
- **Number Mean Diameter**: 32.409
- **Volume Mean Diameter (Mugele & Evans)**: 121.129
- **Volume Mean Diameter (Herdan)**: 449.688
- **Sauter Diameter**: 373.515
- **Area Mean Diameter**: 69.029
- **Standard Deviation of Diameter, by Number**: 60.956
- **Standard Deviation of Volume Diameter (Herdan)**: 125.456
- **Coefficient of Variation of Diameter (Number)**: 1.881
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.279

- **Geometric Number Mean Diameter (Median)**: 22.360
- **Geometric Volume Mean Diameter (Median)**: 426.304
- **Geometric Standard Deviation of Number Diameter**: 1.855
- **Geometric Std Dev of Volume Diameter**: 1.461
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### Statistics per Run

- **Total Droplet Count in a Run:** 154.375
- **Number Mean Diameter:** 182.212
- **Volume Mean Diameter (Mugele & Evans):** 228.927
- **Volume Mean Diameter (Herdan):** 266.783
- **Salted Diameter:** 271.919
- **Area Mean Diameter:** 210.222
- **Standard Deviation of Diameter, by Number:** 105.186
- **Standard Deviation of Volume Dia (Herdan):** 52.404
- **Coefficient of Variation of Diameter (Number):** 0.577
- **Coefficient of Var. of Volume Mean Diameter (Herdan):** 0.183
- **Geometric Number Mean Diameter (Median):** 143.630
- **Geometric Volume Mean Diameter (Median):** 280.730
- **Geometric Standard Deviation of Number Diameter:** 2.144
- **Geometric Std Dev of Volume Diameter:** 1.252
DROPLET DISTRIBUTION PER RUN

DISC NO. 4 / DISC SPEED= 3000 RPM / POTENTIAL = 8.0 KV

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STATISTICS PER RUN

TOTAL DROPLET SPOT NUMBER IN A RUN

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VOLUME MEAN DIAMETER( MUG ELE & EVANS )

VOLUME MEAN DIAMETER( HERDAN )

SALTER DIAMETER

AREA MEAN DIAMETER

STANDARD DEVIATION OF DIAMETER, BY NUMBER

STANDARD DEVIATION OF VOLUME DIAMETER

COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)

COEFF. OF VAR. OF VOLUME MEAN DIAMETER

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN)

GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN)

GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER

GEOMETRIC STD DEV OF VOLUME DIAMETER

252
DROPLET DISTRIBUTION PER RUN
DISC NO. 4 / DISC SPEED=3000. RPM / POTENTIAL=-22.0 KV

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STATISTICS PER RUN
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VOLUME MEAN DIAMETER( MUGLE & EVANS ) ......................... 205.711
VOLUME MEAN DIAMETER( HERDAN ) ................................ 324.324
SALTER DIAMETER .................................................. 295.297
AREA MEAN DIAMETER ................................................ 171.832
STANDARD DEVIATION OF DIAMETER, BY NUMBER .................... 115.362
STANDARD DEVIATION OF VOLUME DIA(HERDAN) ...................... 73.666
COEFFICIENT OF VARIATION OF DIAMETER( NUMBER ) ............. 0.905
COEFFIENT OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) .......... 0.227

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ....................... 84.346
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ....................... 313.181
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| GECCM, STANDARD DEVIATION OF NUMBER DIAMETER | 2.298 |
| GECCM, STIC DEV OF VOLUME DIAMETER | 1.374 |
**DROPLET DISTRIBUTION PER RUN**

**DISC NO. 4 / DISC SPEED=6000 RPM / POTENTIAL= 0.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**................................. 472,267
- **NUMBER MEAN DIAMETER** ............................................. 138.644
- **VOLUME MEAN DIAMETER (MUGLE & EVANS)** ................................ 176.273
- **VOLUME MEAN DIAMETER (HERDAN)** .................................... 238.273
- **SAUTER DIAMETER** .................................................. 215.785
- **AREA MEAN DIAMETER** ............................................... 159.443
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER** ....................... 78.823
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)** ...................... 62.637
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)** .................. 0.569
- **COEFF. OF VARI. OF VOLUME MEAN DIAMETER (HERDAN)** ............... 0.263

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)** .......................... 114.955
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)** ........................ 228.383
- **GEOM. STANDARD DEVIATION OF NUMBER DIAMETER** .................... 1.906
- **GEOMETRIC STD DEV OF VOLUME DIAMETER** ............................. 1.365
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 4 / DISC SPEED=6000 RPM / POTENTIAL= -8.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPCT NUMBER IN A RUN**: 474.410
- **NUMBER MEAN DIAMETER**: 141.521
- **VOLUME MEAN DIAMETER (MUGELE & EVANS)**: 182.985
- **VOLUME MEAN DIAMETER (HERDAN)**: 260.192
- **SALTER DIAMETER**: 227.881
- **AREA MEAN DIAMETER**: 164.100
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 83.15b
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN)**: 88.397
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.588
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.340

- **GECMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 114.583
- **GECMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 244.708
- **GEC. STAND. DEVIATION OF NUMBER DIAMETER**: 2.023
- **GECMETRIC STD DEV OF VOLUME DIAMETER**: 1.436
## DROPLET DISTRIBUTION PER RUN

**Class No. 4** / **Disc Speed=6000. RPM** / **Potential= 8.0 KV**

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**Statistics per Run**

- **Total Droplet Spot Number in a Run**: 909.005
- **Number Mean Diameter**: 97.351
- **Volume Mean Diameter (Muget & Evans)**: 150.862
- **Volume Mean Diameter (Herdan)**: 242.256
- **Salter Diameter**: 214.998
- **Area Mean Diameter**: 126.468
- **Standard Deviation of Diameter, by Number**: 80.771
- **Standard Deviation of Volume Dia (Herden)**: 64.407
- **Coefficient of Variation of Diameter (Number)**: 0.830
- **Coefficient of Var. of Volume Mean Diameter (Herden)**: 0.266
- **Geometric Number Mean Diameter (Median)**: 71.610
- **Geometric Volume Mean Diameter (Median)**: 231.369
- **Geometric Standard Deviation of Number Diameter**: 2.141
- **Geometric Std Dev of Volume Diameter**: 1.397
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 4 / DISC SPEED=6000. RPM / POTENTIAL=-22.0 KV**

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### STATISTICS PER RUN

- **Total DROPLET SPOT NUMBER IN A RUN**: 1199.942
- **Number Mean Diameter**: 98.890
- **Volume Mean Diameter (Mugele & Evans)**: 166.047
- **Volume Mean Diameter (Herdan)**: 278.559
- **Salter Diameter**: 249.037
- **Area Mean Diameter**: 135.690
- **Standard Deviation of Diameter, by Number**: 92.950
- **Standard Deviation of Volume Diameter (Herdan)**: 66.294
- **Coefficient of Variation of Diameter (Number)**: 0.940
- **Coefficient of Variation of Volume Diameter (Herdan)**: 0.245

- **Geometric Number Mean Diameter (Median)**: 67.462
- **Geometric Volume Mean Diameter (Median)**: 267.342
- **Geometric Standard Deviation of Number Diameter**: 2.337
- **Geometric Standard Deviation of Volume Diameter**: 1.378
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 4** / **DISC SPEED=6000 RPM** / **POTENTIAL= 22.0 KV**

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### STATISTICS PER RUN

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 953.324
- **NUMBER MEAN DIAMETER**: 94.937
- **VOLUME MEAN DIAMETER (MUGLE & EVANS)**: 137.461
- **VOLUME MEAN DIAMETER (HERDAN)**: 221.362
- **SALTER DIAMETER**: 190.333
- **AREA MEAN DIAMETER**: 116.904
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 68.253
- **STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN)**: 66.698
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.719
- **COEFFICIENT OF VARIATION OF VOLUME MEAN DIAMETER (HERDAN)**: 0.301

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 76.405
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 208.429
- **GEOMETRIC STANDARD DEV OF VOLUME DIAMETER**: 1.888
DROPLET DISTRIBUTION PER RUN

**DISC NO. 4**
**DISC SPEED = 9000 RPM**
**POTENTIAL = 0.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 3110.877
- **NUMBER MEAN DIAMETER**: 82.248
- **VOLUME MEAN DIAMETER (Mugele & Evans)**: 111.262
- **VOLUME MEAN DIAMETER (Herdan)**: 182.602
- **SALTER DIAMETER**: 147.963
- **AREA MEAN DIAMETER**: 96.549
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 50.575
- **STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN)**: 78.306
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.615
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.429

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 69.435
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 165.719
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.788
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.579
DROPLET DISTRIBUTION PER RUN

DISC NO. 4 / DISC SPEED=9000 RPM / POTENTIAL= -8.0 KV

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STATISTICS PER RUN

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VOLUME MEAN DIAMETER( HERDAN ) ........................................ 170.968
SALTER DIAMETER .............................................................. 144.626
AREA MEAN DIAMETER .......................................................... 93.183
STANDARD DEVIATION OF DIAMETER, BY NUMBER ...................... 50.949
STANDARD DEVIATION OF VOLUME DIAM(HERDAN) ....................... 57.012
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ................. 0.653
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ................ 0.333

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ........................... 64.405
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ............................. 159.335
GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER ............ 1.852
GEOMETRIC STD DEV OF VOLUME DIAMETER ............................... 1.500
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### STATISTICS PER RUN

- Total droplet spot number in a run: 2834.022
- Number mean diameter: 72.854
- Volume mean diameter (MuGeme & Evans): 104.053
- Volume mean diameter (Herdan): 172.027
- Salters diameter: 143.649
- Area mean diameter: 88.620
- Standard deviation of diameter, by number: 50.465
- Standard deviation of volume (Herdan): 58.307
- Coefficient of variation of diameter (number): 0.693
- Coeff. of var. of volume mean diameter (Herdan): 0.339
- Geometric number mean diameter (median): 58.908
- Geometric volume mean diameter (median): 159.588
- Geometric standard deviation of number diameter: 1.912
- Geometric std. dev. of volume diameter: 1.523
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 4 | DISC SPEED=9000 RPM | POTENTIAL=-22.0 KV**

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**STATISTICS PER RUN**

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| GEOMETRIC VOLUME MEAN DIA(MEDIAN) | 156.243  |
| GEOME. STANDARD DEVIATION DIAMETER | 2.009    |
| GEOMETRIC STD DEV OF VOLUME DIA    | 1.518    |
## Droplet Distribution Per Run

**DISC NO. 4 / DISC SPEED=9000 RPM / POTENTIAL= 22.0 KV**

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**Statistics Per Run**

- **Total Droplet Spot Number in a Run**: 3208.497
- **Number Mean Diameter**: 77.883
- **Volume Mean Diameter (Mugele & Evans)**: 99.884
- **Volume Mean Diameter (Herdan)**: 150.065
- **Saltier Diameter**: 126.286
- **Area Mean Diameter**: 88.893
- **Standard Deviation of Diameter, by Number**: 42.858
- **Standard Deviation of Volume Diameter (Herdan)**: 56.787
- **Coefficient of Variation of Diameter (Number)**: 0.550
- **Coeff. of Var. of Volume Mean Diameter (Herdan)**: 0.378

- **Geometric Number Mean Diameter (Median)**: 67.473
- **Geometric Volume Mean Diameter (Median)**: 138.652
- **Geometric Standard Deviation of Number Diameter**: 1.719
- **Geometric Std Dev of Volume Diameter**: 1.514
XVI. APPENDIX F. RADIAL DISTRIBUTION BY RUN
### Droplet Distribution Per Run

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**Statistics per Run**

- Total Droplet Spot Number in a Run: 67,541
- Number Mean Diameter (Mušek & Evans): 208.432
- Volume Mean Diameter (MUšek & Evans): 267.005
- Volume Mean Diameter (HERDAN): 373.734
- Sauter Diameter: 330.364
- Area Mean Diameter: 240.241
- Standard Deviation of Diameter, by Number: 120.356
- Standard Deviation of Volume Diameter (HERDAN): 116.392
- Coefficient of Variation of Diameter (Number): 0.577
- Coefficient of Variation of Volume Mean Diameter (HERDAN): 0.311

- Geometric Number Mean Diameter (Median): 170.953
- Geometric Volume Mean Diameter (Median): 353.608
- Geometric Standard Deviation of Number Diameter: 1.984
- Geometric Standard Deviation of Volume Diameter: 1.418
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## Statistics Per Run

- Total Droplet Spot Number in a Run: 76,340
- Number Mean Diameter: 221.493
- Volume Mean Diameter: 268.940
- Sauter Mean Diameter: 366.831
- Area Mean Diameter: 321.471
- Standard Deviation of Diameter, by Number: 108.191
- Standard Deviation of Volume Diameter (Herdan): 121.437
- Coefficient of Variation of Diameter (Number): 0.488
- Coefficient of Variation of Volume Diameter (Herdan): 0.331

- Geometric Number Mean Diameter (Median): 193.120
- Geometric Volume Mean Diameter (Median): 344.976
- Geometric Standard Deviation of Number Diameter: 1.768
- Geometric Std Dev of Volume Diameter: 1.438
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### STATISTICS PER RUN

- TOTAL DROPLET SPOT NUMBER IN A RUN: 123,169
- NUMBER MEAN DIAMETER: 222.323
- VOLUME MEAN DIAMETER (MUGGLE & EVANS): 274.556
- VOLUME MEAN DIAMETER (HERDAN): 370.149
- SALTER DIAMETER: 330.104
- AREA MEAN DIAMETER: 250.603
- STANDARD DEVIATION OF DIAMETER, BY NUMBER: 116.122
- STANDARD DEVIATION OF VOLUME DIA (HERDAN): 111.695
- COEFFICIENT OF VARIATION OF DIAMETER (NUMBER): 0.522
- COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN): 0.302

- GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN): 188.040
- GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN): 351.376
- GEOM. STANDARD DEVIATION OF NUMBER DIAMETER: 1.885
- GEOMETRIC STC DEV OF VOLUME DIAMETER: 1.401
DRUPLET DISTRIBUTION PER RUN

DISC NO. 2 / DISC SPEED=3000. RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN

TOTAL DROPLET SPLIT NUMBER IN A RUN .......... 114,290
NUMBER MEAN DIAMETER( ) ................................ 205.093
VOLUME MEAN DIAMETER( MUGELE & EVANS ) .......... 254.652
VOLUME MEAN DIAMETER( HERDAN ) .................. 334.140
SALTER DIAMETER ...................................... 305.415
AREA MEAN DIAMETER .................................... 232.721
STANDARD DEVIATION OF DIAMETER, BY NUMBER ....... 110.467
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN) ... 85.876
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) ... 0.539
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ... 0.257

GEOMETRIC NUMBER MEAN DIAMETER(MEDIAN) ............ 172.210
GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) ............ 321.386
GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER ... 1.887
GEOMETRIC STD DEV OF VOLUME DIAMETER ............... 1.344
## Droplet Distribution Per Run

**DISC NO. 2** / **DISC SPEED = 6000 RPM** / **POTENTIAL = 0.0 KV**

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**Statistics Per Run**

- **Total Droplet Spot Number in a Run**: 257,853
- **Number Mean Diameter**: 189.624
- **Volume Mean Diameter (Mugele & Evans)**: 221.382
- **Volume Mean Diameter (Herdan)**: 268.256
- **Sauter Diameter**: 251.821
- **Area Mean Diameter**: 207.740
- **Standard Deviation of Diameter, by Number**: 85.010
- **Standard Deviation of Volume Diameter (Herdan)**: 57.733
- **Coefficient of Variation of Diameter (Number)**: 0.448
- **Coefficient of Variation of Volume Diameter (Herdan)**: 0.215

- **Geometric Number Mean Diameter (Median)**: 165.687
- **Geometric Volume Mean Diameter (Median)**: 260.980
- **Geometric Standard Deviation of Number Diameter**: 1.771
- **Geometric Std Dev of Volume Diameter**: 1.282
### Droplet Distribution Per Run

**Disc No. 2 / Disc Speed = 6000 RPM / Potential = -8.0 KV**

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**Statistics Per Run**

- **Total Droplet Spot Number In A Run**: 367,210
- **Mean Diameter**:
  - Number: 132.391
  - Mugele & Evans: 155.460
  - Herdan: 198.829
- **Standard Deviation of Diameter**:
  - Area Number: 1.618
  - Area Volume: 1.368
- **Coefficient of Variation**:
  - Diameter (Number): 0.439
  - Diameter (Herdan): 0.280
  - Volume Diameter: 0.076

**Geometric Measures**

- **Geometric Number Mean Diameter (Median)**: 119.114
- **Geometric Volume Mean Diameter (Median)**: 150.100
- **Geometric Standard Deviation of Diameter**: 1.618
- **Geometric Std Dev of Volume Diameter**: 1.368
### DROPLET DISTRIBUTION PER RUN

CISC NO. 2 / DISC SPEED=6000 RPM / POTENTIAL= 8.0 KV

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### STATISTICS PER RUN

TOTAL DROPLET SPOT NUMBER IN A RUN: 270.883

- **NUMBER MEAN DIAMETER:** 133.551
- **VOLUME MEAN DIAMETER (MUGELE & EVANS):** 153.346
- **VOLUME MEAN DIAMETER (HERDAN):** 189.245
- **SLATER DIAMETER:** 173.898
- **AREA MEAN DIAMETER:** 144.180
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER:** 54.431
- **STANDARD DEVIATION OF VOLUME DIA (HERDAN):** 49.298
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER):** 0.408
- **COEFFICIENT OF VARIATION OF VOLUME MEAN DIAMETER (MEDIAN):** 0.264
- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN):** 121.248
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN):** 162.038
- **GEOMETR. STANDARD DEVIATION OF NUMBER DIAMETER:** 1.597
- **GEOMETRIC STD DEV OF VOLUME DIAMETER:** 1.336
## Droplet Distribution per Run

**Disc No.: 2** / **Disc Speed:** 6000 RPM / **Potential:** -22.0 KV

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## Statistics per Run

- **Total Droplet Sput Number in a Run:** 407,922
- **Number Mean Diameter:** 134.033
- **Volume Mean Diameter:** 159.275
- **Volume Mean Diameter (Herdan):** 202.586
- **Sauter Diameter:** 185.450
- **Area Mean Diameter:** 147.720
- **Standard Deviation of Diameter, by Number:** 62.176
- **Standard Deviation of Volume Diameter:** 51.334
- **Coefficient of Variation of Diameter (Number):** 0.464
- **Coefficient of Variation of Volume Diameter:** 0.253

- **Geometric Number Mean Diameter (Median):** 118.471
- **Geometric Volume Mean Diameter (Median):** 194.877
- **Geometric Standard Deviation of Diameter:** 1.688
- **Geometric Std Dev of Volume Diameter:** 1.343
DROPLET DISTRIBUTION PER RUN

CISC NO. 2 / DISC SPEED=60000. RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN

TOTAL DROPLET SPOT NUMBER IN A RUN ....................... 544,939
NUMBER MEAN DIAMETER( ) ..................................... 145.675
VOLUME MEAN DIAMETER( MUGGLE & EVANS ) ................... 173.660
VOLUME MEAN DIAMETER( HERDAN ) ............................ 223.611
SAUTER DIAMETER ................................................. 203.083
AREA MEAN DIAMETER ............................................. 160.712
STANDARD DEVIATION OF DIAMETER, BY NUMBER ............. 67.938
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN) ... 61.089
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) .... 0.466
COEFF. OF VARI. OF VOLUME MEAN DIAMETER(HERDAN) ... 0.273

CECMETRIC NUMBER MEAN DIAMETER(MEDIAN) ................. 128.825
CECMETRIC VOLUME MEAN DIAMETER(MEDIAN) .................. 214.176
CECM. STANDARD DEVIATION OF NUMBER DIAMETER ....... 1.684
CECMETRIC STDEV OF VOLUME DIAMETER ....................... 1.361
### DROPLET DISTRIBUTION PER RUN

**Class No. 2**  
**Disc Speed = 9000. RPM**  
**Potential = 0.0 KV**

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| Geometric Stc Dev Of Volume Diameter | 1.338 |</p>
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| VOLUME | 960.613 |

**Geometric mean diameter of volume**

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**Statistics per Run**

960.613
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=9000 RPM / POTENTIAL=-22.0 KV**

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| GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN) | 153.753 |
| GEOM. STANDARD DEVIATION OF NUMBER DIAMETER | 1.863 |
| GEOMETRIC STD DEV OF VOLUME DIAMETER | 1.297 |
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 2 / DISC SPEED=9000 RPM / POTENTIAL= 22.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 915.740
- **NUMBER MEAN DIAMETER**: 115.287
- **VOLUME MEAN DIAMETER (MUGELE & EVANS)**: 137.598
- **VOLUME MEAN DIAMETER (HERDAN)**: 178.200
- **SAUTER DIAMETER**: 161.120
- **AREA MEAN DIAMETER**: 127.252
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 53.901
- **STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN)**: 49.453
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.468
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.278

- **GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 101.121
- **GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 170.307
- **GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.740
- **GEOMETRIC STD DEV OF VOLUME DIAMETER**: 1.372
| Coefficient of Variation of Diameter (Number) | 8.6119 |
| Coefficient of Variation of Diameter (Median) | 3.3562 |
| Coefficient of Variation of Diameter (Mean) | 3.4165 |
| Geometric Mean Diameter (Median) | 2.025 |
| Geometric Mean Diameter (Number) | 2.282 |
| Geometric Mean Diameter (Mean) | 2.374 |
| Geometric Standard Deviation of Diameter | 2.006 |
| Number Diameter (Angle of Distribution) | 2.664 |
| Total Dropped Spot Number in a Run | 83.958 |

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Distribution of Droplet Diameter Per Run

Class No. 3

No. Ave. Dia. Number Volume Fraction Cumulative Cumulative

Class No. 3

Disc Speed=3000 RPM / Potential=0.0 KV
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 3 / DISC SPEED=3000 RPM / POTENTIAL= -8.0 KV**

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### STATISTICS PER RUN

- **Total Droplet Spot Number in a Run**: 126.602
- **Number Mean Diameter**: 251.185
- **Volume Mean Diameter (Mugele & Evans)**: 315.662
- **Volume Mean Diameter (Herdan)**: 396.767
- **Sauter Diameter**: 372.900
- **Area Mean Diameter**: 290.678
- **Standard Deviation of Diameter, by Number**: 146.868
- **Standard Deviation of Volume Diameter (Herdan)**: 89.198
- **Coefficient of Variation of Diameter (Number)**: 0.585
- **Coefficient of Var. of Volume Diameter (Herdan)**: 0.225

- **Geometric Number Mean Diameter (Median)**: 185.423
- **Geometric Volume Mean Diameter (Median)**: 385.837
- **Geometric Standard Deviation of Number Diameter**: 2.514
- **Geometric Std Dev of Volume Diameter**: 1.279
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 3 / DISC SPEED=3000. RPM / POTENTIAL= 8.0 KV**

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DROPLET DISTRIBUTION PER RUN

DISC NO. 3 / DISC SPEED=3000. RPM / POTENTIAL=-22.0 KV

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STATISTICS PER RUN

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VOLUME MEAN DIAMETER( HERDAN ) .......................... 323.705
SALTER DIAMETER ........................................... 305.457
AREA MEAN DIAMETER ........................................ 245.448
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GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER .... 1.873
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## Droplet Distribution Per Run

**Disc No. 3 / Disc Speed=3000 RPM / Potential= 22.0 KV**

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### Statistics Per Run

- **Total Droplet Spot Number in a Run**: 186.253
- **Number Mean Diameter (Mugele & Evans)**: 209.117
- **Volume Mean Diameter (Mugele & Evans)**: 250.769
- **Volume Mean Diameter (Herdan)**: 320.203
- **Salter Diameter**: 293.682
- **Area Mean Diameter**: 231.917
- **Standard Deviation of Diameter, By Number**: 100.549
- **Standard Deviation of Volume Diameter (Herdan)**: 79.253
- **Coefficient of Variation of Diameter (Number)**: 0.481
- **Coefficient of Variation of Volume Diameter (Herdan)**: 0.248

- **Geometric Number Mean Diameter (Median)**: 182.413
- **Geometric Volume Mean Diameter (Median)**: 308.634
- **Geometric Standard Deviation of Number Diameter**: 1.752
- **Geometric Standard Deviation of Volume Diameter**: 1.338
## Droplet Distribution Per Run

**Disc No. 3 / Disc Speed=6000 RPM / Potential= 0.0 KV**

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### Statistics Per Run

- **Total Droplet Spot Number in a Run**: 449.975
- **Number Mean Diameter**: 134.684
- **Volume Mean Diameter**: 179.762
- **Volume Mean Diameter**: 243.786
- **Salter Diameter**: 225.489
- **Area Mean Diameter**: 160.629
- **Standard Deviation of Diameter, by Number**: 87.630
- **Standard Deviation of Volume Diameter**: 53.027
- **Coefficient of Variation of Diameter (Number)**: 0.651
- **Coefficient of Variation of Volume Mean Diameter (Herdan)**: 0.218

**Geometric Number Mean Diameter (Median)**: 104.115
**Geometric Volume Mean Diameter (Median)**: 236.352
**Geometric Standard Deviation of Number Diameter**: 2.142
**Geometric Std Dev of Volume Diameter**: 1.313
DROPLET DISTRIBUTION PER RUN

CLASS NO. 3 / DISC SPEED=6000 RPM / POTENTIAL= -8.0 KV

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## Droplet Distribution Per Run

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### Statistics Per Run

- **Total Droplet Spot Number in a Run**: 270,003
- **Mean Diameter (Number)**: 178.625
- **Mean Diameter (Volume, Mugele & Evans)**: 223.688
- **Mean Diameter (Herdan)**: 294.047
- **Sauter Diameter**: 269.558
- **Area Mean Diameter**: 203.535
- **Standard Deviation of Diameter, by Number**: 98.582
- **Standard Deviation of Volume Diameter (Herdan)**: 65.753
- **Coefficient of Variation of Diameter (Number)**: 0.552
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.237

- **Geometric Number Mean Diameter (Median)**: 146.309
- **Geometric Volume Mean Diameter (Median)**: 283.531
- **Geometric Standard Deviation of Number Diameter**: 2.018
- **Geometric Std Dev of Volume Diameter**: 1.338
### Droplet Distribution Per Run

**Disc No. 3 / Disc Speed=6000 RPM / Potential=-22.0 KV**

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**Statistics Per Run**

- Total droplet spot number in a run: 490.413
- Number mean diameter: 156.417
- Volume mean diameter (Mugel & Evans): 192.247
- Volume mean diameter (Herdan): 251.414
- Sauter diameter: 229.593
- Area mean diameter: 176.057
- Standard deviation of diameter, by number: 80.889
- Standard deviation of volume diameter (Herdan): 61.820
- Coefficient of variation of diameter (number): 0.517
- Coefficient of variance of volume mean diameter (Herdan): 0.246

<p>| Geometric number mean diameter (median) | 133.870 |
| Geometric volume mean diameter (median) | 241.950 |
| Geometric standard deviation of number diameter | 1.809 |
| Geometric std dev of volume diameter | 1.347 |</p>
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**Statistics per Run**

- Total Droplet Spot Number in a Run: 459.318
- Number Mean Diameter (Mugel & Evans): 154.047
- Volume Mean Diameter (Herdan): 212.673
- Salter Diameter: 309.298
- Area Mean Diameter: 278.192
- Standard Deviation of Diameter, by Number: 104.528
- Standard Deviation of Volume Dia (Herdan): 75.231
- Coefficient of Variation of Diameter (Number): 0.679
- Coefficient of Variation of Volume Mean Diameter (Herdan): 0.243

- Geometric Number Mean Diameter (Median): 121.317
- Geometric Volume Mean Diameter (Median): 296.034
- Geometric Standard Deviation of Number Diameter: 2.040
- Geometric Stc Dev of Volume Diameter: 1.374
## DROPLET DISTRIBUTION PER RUN

**DISC NO. 3 / DISC SPEED=9000 RPM / POTENTIAL= 0.0 KV**

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**STATISTICS PER RUN**

| TOTAL DROPLET SPOT NUMBER IN A RUN | 1488.592 |
| NUMBER MEAN DIAMETER | 114.421 |
| VOLUME MEAN DIAMETER | 140.443 |
| VOLUME MEAN DIAMETER (HERDAN) | 182.307 |
| SAUTER DIAMETER | 167.299 |
| AREA MEAN DIAMETER | 126.774 |
| STANDARD DEVIATION OF DIAMETER, BY NUMBER | 59.100 |
| STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN) | 44.087 |
| COEFFICIENT OF VARIATION OF DIAMETER (NUMBER) | 0.517 |
| COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN) | 0.242 |
| GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN) | 98.276 |
| GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN) | 175.817 |
| GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER | 1.779 |
| GEOMETRIC STD DEV OF VOLUME DIAMETER | 1.335 |
## Droplet Distribution Per Run

**DISC No. 3 / DISC SPEED = 9000 RPM / POTENTIAL = -8.0 KV**

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**STATISTICS PER RUN**

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| VOLUME MEAN DIAMETER (HERDAN) | 181.714 |
| AREA MEAN DIAMETER | 166.135 |
| STANDARD DEVIATION OF DIAMETER, BY NUMBER | 56.549 |
| STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN) | 49.947 |
| COEFFICIENT OF VARIATION OF DIAMETER (NUMBER) | 0.473 |
| COEFF. OF VARIATION OF VOLUME MEAN DIAMETER (HERDAN) | 0.275 |
| GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN) | 104.331 |
| GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN) | 174.487 |
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**Class Group Proportion Fraction Cumulative Cumulative**

**Size No. 3 Disc Speed=9000 Rpm / Percentile=22.0 Kv**

**Drum Distribution For Run**
DROPLET DISTRIBUTION PER RUN
CISC NO. 3 / DISC SPEED=9000. RPM / POTENTIAL= 22.0 KV

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STATISTICS PER RUN
TOTAL DROPLET SPOT NUMBER IN A RUN ..................... 973.379
NUMBER MEAN DIAMETER( ) .................................... 118.576
VOLUME MEAN DIAMETER( MUGELE & EVANS ) .................. 141.440
VOLUME MEAN DIAMETER( HERDAN ) .......................... 178.854
SAUTER DIAMETER ............................................ 164.529
AREA MEAN DIAMETER ........................................ 131.237
STANDARD DEVIATION OF DIAMETER, BY NUMBER .............. 56.270
STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN) ......... 44.017
COEFFICIENT OF VARIATION OF DIAMETER (NUMBER) ........ 0.475
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GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER ....... 1.829
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- **No.:** 4
- **Disc Speed:** 3000 RPM
- **Potential:** 0.0 KV

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**Statistics per Run**

- **Total Droplet Spot Number in a Run:** 1002.634
- **Number Mean Diameter:** 39.104
- **Volume Mean Diameter (Mugel & Evans):** 148.923
- **Volume Mean Diameter (Herdan):** 460.673
- **Salter Diameter:** 407.219
- **Area Mean Diameter:** 90.127
- **Standard Deviation of Diameter, by Number:** 81.242
- **Standard Deviation of Volume Diameter (Herdan):** 119.865
- **Coefficient of Variation of Diameter (Number):** 2.078
- **Coefficient of Variation of Volume Diameter (Herdan):** 0.260

- **Geometric Number Mean Diameter (Median):** 22.863
- **Geometric Volume Mean Diameter (Median):** 442.279
- **Geometric Standard Deviation of Number Diameter:** 2.086
- **Geometric Std. Dev. of Volume Diameter:** 1.371
## DROPLET DISTRIBUTION PER RUN

**CISC No. 4 / Disc Speed=3000 RPM / Potential= -8.0 KV**

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<th>FRACTION</th>
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## STATISTICS PER RUN

- **Total Droplet Spot Number in a Run**: 107,200
- **Number Mean Diameter**: 212.464
- **Volume Mean Diameter (Mugele & Evans)**: 250.334
- **Volume Mean Diameter (Herdan)**: 292.461
- **Salter Diameter**: 282.064
- **Area Mean Diameter**: 236.029
- **Standard Deviation of Diameter, by Number**: 103.246
- **Standard Deviation of Volume Diameter (Herdan)**: 47.030
- **Coefficient of Variation of Diameter (Number)**: 0.486
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.161

- **Geometric Number Mean Diameter (Median)**: 173.236
- **Geometric Volume Mean Diameter (Median)**: 288.031
- **GECM. Standard Deviation of Number Diameter**: 2.106
- **GECM. Std. Dev. of Volume Diameter**: 1.204
### Droplet Distribution Per Run

**Disc No. 4**  /  **Disc Speed=3000. RPM**  /  **Potential= 8.0 KV**

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**Statistics Per Run**

- Total DROPLET SPCT NUMBER IN A RUN: 469,446
- Number Mean Diameter (Jaeger & Evans): 68.843
- Volume Mean Diameter (Herdan): 339.532
- Sauter Diameter: 309.623
- Area Mean Diameter: 121.619
- Standard Deviation of Diameter, by Number: 100.366
- Standard Deviation of Volume Diameter (Herdan): 73.331
- Coefficient of Variation of Diameter (Number): 1.458
- Coeff. of Var. of Volume Mean Diameter (Herdan): 0.216

**Geometric**

- Number Mean Diameter (Median): 36.474
- Volume Mean Diameter (Median): 328.925
- Standard Deviation of Number Diameter: 2.650
- Standard Deviation of Volume Diameter: 1.327
### DROPLET DISTRIBUTION PER RUN

**DISC NO. 4 / DISC SPEED=3000 RPM / POTENTIAL=-22.0 KV**

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#### STATISTICS PER RUN

| TOTAL DROPLET SPOT NUMBER IN A RUN          | 301.641 |
| NUMBER MEAN DIAMETER( )                      | 166.617 |
| VOLUME MEAN DIAMETER( MUGLE & EVAAS )        | 242.304 |
| VOLUME MEAN DIAMETER( HERDAN )               | 331.485 |
| SALTER DIAMETER                              | 312.722 |
| AREA MEAN DIAMETER                           | 213.461 |
| STANDARD DEVIATION OF DIAMETER, BY NUMBER    | 131.114 |
| STANDARD DEVIATION OF VOLUME DIAM (HERDAN)   | 64.658  |
| COEFFICIENT OF VARIATION OF DIAMETER (NUMBER) | 0.778  |
| COEFF. OF VAR. OF VOLUME MEAN DIAM (HERDAN)  | 0.195   |

| GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN)     | 111.364 |
| GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN)     | 323.870 |
| GEOM. STANDARD DEVIATION OF NUMBER DIAMETER | 2.677   |
| GEOMETRIC STD DEV OF VOLUME DIAMETER        | 1.262   |
## DROPLET DISTRIBUTION PER RUN

**CLASS** | **CLASS DROPLET FRACTION** | **FRACTION** | **CUMULATIVE NUMBER** | **VOLUME NUMBER** | **CUMULATIVE VOLUME**
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3 | 15.34 | 0.87 | 0.0027 | 0.0000 | 0.0029
4 | 18.26 | 0.93 | 0.0039 | 0.0000 | 0.0058
5 | 21.59 | 0.00 | 0.0000 | 0.0000 | 0.0000
6 | 25.62 | 0.00 | 0.0000 | 0.0000 | 0.0000
7 | 30.40 | 1.89 | 0.0059 | 0.0000 | 0.0117
8 | 36.07 | 27.09 | 0.0843 | 0.0003 | 0.0966
9 | 42.80 | 63.95 | 0.2001 | 0.0012 | 0.2967
10 | 50.79 | 41.21 | 0.1290 | 0.0013 | 0.4257
11 | 50.27 | 17.38 | 0.0544 | 0.0009 | 0.4801
12 | 71.61 | 11.91 | 0.0373 | 0.0010 | 0.5174
13 | 84.65 | 9.56 | 0.0360 | 0.0014 | 0.5473
14 | 100.68 | 4.51 | 0.0141 | 0.0011 | 0.5614
15 | 115.47 | 5.67 | 0.0177 | 0.0023 | 0.5792
16 | 141.76 | 7.67 | 0.0243 | 0.0035 | 0.6032
17 | 168.20 | 9.77 | 0.0306 | 0.0046 | 0.6337
18 | 195.96 | 3.82 | 0.0276 | 0.0063 | 0.6613
19 | 236.62 | 17.09 | 0.0535 | 0.0092 | 0.7148
20 | 281.00 | 33.20 | 0.1039 | 0.0171 | 0.8188
21 | 333.43 | 20.42 | 0.0627 | 0.0228 | 0.9014
22 | 395.64 | 26.23 | 0.0821 | 0.0376 | 0.9835
23 | 465.45 | 5.26 | 0.0165 | 0.0126 | 1.0000
24 | 557.04 | 0.00 | 0.0000 | 0.0000 | 1.0000
25 | 660.56 | 0.00 | 0.0000 | 0.0000 | 1.0000

**STATISTICS PER RUN**

TOTAL DROPLET SPOT NUMBER IN A RUN................................. 319.493
NUMBER MEAN DIAMETER( )............................................. 154.183
VOLUME MEAN DIAMETER( MCGELE & EVANS )............................ 237.552
VOLUME MEAN DIAMETER( HERDAN )..................................... 352.804
SALTER DIAMETER .......................................................... 326.376
AREA MEAN DIAMETER ..................................................... 202.831
STANDARD DEVIATION OF DIAMETER, BY NUMBER......................... 131.996
STANDARD DEVIATION OF VOLUME DIA(HERDAN).......................... 76.071
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)...................... 0.856
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN).................... 0.216

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GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN).............................. 342.355
GEOM. STANDARD DEVIATION OF NUMBER DIAMETER....................... 2.486
GEOMETRIC STD DEV OF VOLUME DIAMETER .............................. 1.308
### Droplet Distribution Per Run

**Disc No. 4 / Disc Speed = 6000 RPM / Potential = 0.0 KV**

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**Statistics Per Run**

- **Total Droplet Spot Number in a Run**: 326.721
- **Volume Mean Diameter (Mugele & Evans)**: 144.561
- **Volume Mean Diameter (Herdan)**: 186.674
- **Sauter Diameter**: 248.934
- **Area Mean Diameter**: 168.575
- **Standard Deviation of Diameter, by Number**: 86.849
- **Coefficient of Variation of Diameter (Number)**: 0.601
- **Coefficient of Variation of Volume Mean Diameter (Herdan)**: 0.233

**Geometric**

- **Geometric Number Mean Diameter (Median)**: 116.179
- **Geometric Volume Mean Diameter (Median)**: 240.590
- **Geometric Standard Deviation of Number Diameter**: 2.013
- **Geometric Std Dev of Volume Diameter**: 1.325
### DRUPELT DISTRIBUTION PER RUN

CISC NO. 4 / DISC SPEED=6000. RPM / PCTENTIAL= -8.0 KV

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### STATISTICS PER RUN

- TOTAL DRUPELT SPCT NUMBER IN A RUN: 269.672
- NUMBER MEAN DIAMETER: 171.869
- VOLUME MEAN DIAMETER (MUGLE & EVANS): 208.624
- VOLUME MEAN DIAMETER (HERDAN): 275.091
- SALTER DIAMETER: 246.752
- AREA MEAN DIAMETER: 191.984
- STANDARD DEVIATION OF DIAMETER, BY NUMBER: 85.710
- STANDARD DEVIATION OF VOLUME DIAMETER (HERDAN): 85.549
- COEFFICIENT OF VARIATION OF DIAMETER (NUMBER): 0.499
- COEFFICIENT OF VARIATION OF VOLUME MEAN DIAMETER (HERDAN): 0.311

- GEOMETRIC NUMBER MEAN DIAMETER (MEDIAN): 146.228
- GEOMETRIC VOLUME MEAN DIAMETER (MEDIAN): 261.415
- GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER: 1.875
- GEOMETRIC STANDARD DEV OF VOLUME DIAMETER: 1.388
**Droplet Distribution Per Run**

**Disc No.** 4  
**Disc Speed** = 6000 RPM  
**Potential** = 8.0 KV

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**Statistics Per Run**

- **Total Droplet Spot Number in a Run**: 692.939
- **Number Mean Diameter**: 93.378
- **Volume Mean Diameter (Mugele & Evans)**: 153.424
- **Volume Mean Diameter (Herdan)**: 252.765
- **Saltet Diameter**: 226.922
- **Area Mean Diameter**: 126.250
- **Standard Deviation of Diameter, by Number**: 85.030
- **Standard Deviation of Volume (Herdan)**: 61.515
- **Coefficient of Variation of Diameter (Number)**: 0.911
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.243

- **Geometric Number Mean Diameter (Median)**: 66.161
- **Geometric Volume Mean Diameter (Median)**: 242.580
- **Geometric Standard Deviation of Number Diameter**: 2.194
- **Geometric Std Dev of Volume Diameter**: 1.368
### Droplet Distribution per Run

**Cisc No. 4 / Disc Speed: 6000 RPM / Potential: -22.0 KV**

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**Statistics Per Run**

- Total droplet spot number in a run: 669,358
- Number mean diameter: 118.414
- Volume mean diameter (Mugele & Evans): 189.030
- Volume mean diameter (Herdan): 288.479
- Sauter diameter: 266.507
- Area mean diameter: 159.325
- Standard deviation of diameter, by number: 106.676
- Standard deviation of volume: Herdan: 61.951
- Coefficient of variation of diameter (number): 0.901
- Coefficient of variation of volume mean diameter (Herdan): 0.215

Geometric number mean diameter (median): 77.962
Geometric volume mean diameter (median): 279.999
Geometric standard deviation of number diameter: 2.493
Geometric std dev of volume diameter: 1.309
DROPLET DISTRIBUTION PER RUN

CISC NO. 4 / DISC SPEED=6000 RPM / POTENTIAL=22.0 KV

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STATISTICS PER RUN

TOTAL DROPLET SPOT NUMBER IN A RUN .......... 400.156
NUMBER MEAN DIAMETER( ) .................................. 126.014
VOLUME MEAN DIAMETER( MUGELE & EVANS )........... 169.482
VOLUME MEAN DIAMETER( HERDAN ) ....................... 236.822
SALTER DIAMETER ........................................... 215.339
AREA MEAN DIAMETER ....................................... 150.473
STANDARD DEVIATION OF DIAMETER, BY NUMBER ........ 82.337
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN) .... 59.097
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER) .... 0.653
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN) ... 0.250

GECMETRIC NUMBER MEAN DIAMETER(MEDIAN) .......... 98.945
GECMETRIC VOLUME MEAN DIAMETER(MEDIAN) .......... 227.743
GECMETRIC STANDARD DEVIATION OF NUMBER DIAMETER ... 2.062
GECMETRIC STANDARD DEVIATION OF VOLUME DIAMETER ... 1.353
## Droplet Distribution Per Run

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### Statistics Per Run

- **Total Driplete Spect Number in a Run:** 2480.352
- **Number Mean Diameter:** 78.787
- **Volume Mean Diameter:** 109.952
- **Volume Mean Diameter (Herdan):** 192.669
- **Sauter Diameter:** 151.729
- **Area Mean Diameter:** 93.665
- **Standard Deviation of Diameter, by Number:** 50.664
- **Standard Deviation of Volume Diameter (Herdan):** 84.169
- **Coefficient of Variation of Diameter (Number):** 0.643
- **Coefficient of Var. of Volume Mean Diameter (Herdan):** 0.437

- **Geometric Number Mean Diameter (Median):** 66.531
- **Geometric Volume Mean Diameter (Median):** 173.061
- **Geometric Standard Deviation of Number Diameter:** 1.767
- **Geometric Stc Dev of Volume Diameter:** 1.629
DROPLET DISTRIBUTION PER RUN

CISC No. 4 / DISC SPEED = 9000. RPM / PCTENTIAL = -8.0 KV

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STATISTICS PER RUN

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VOLUME MEAN DIAMETER( HERDAN )............................. 176.265
SALTIER DIAMETER.................................................. 147.720
AREA MEAN DIAMETER............................................... 92.251
STANDARD DEVIATION OF DIAMETER, BY NUMBER............. 51.508
STANDARD DEVIATION OF VOLUME DIAMETER(HERDAN)......... 58.806
COEFFICIENT OF VARIATION OF DIAMETER(NUMBER)........ 0.673
COEFF. OF VAR. OF VOLUME MEAN DIAMETER(HERDAN)....... 0.334

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GEOMETRIC VOLUME MEAN DIAMETER(MEDIAN).................. 163.855
GEOMETRIC STANDARD DEVIATION OF NUMBER DIAMETER..... 1.836
GEOMETRIC STD DEV OF VOLUME DIAMETER................. 1.516
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### Statistics per Run

- **Total Droplet Spot Number in a Run**: 1898.626
- **Number Mean Diameter**: 77.661
- **Volume Mean Diameter (Mugele & Evans)**: 110.588
- **Volume Mean Diameter (Herdan)**: 180.020
- **Salter Diameter**: 152.089
- **Area Mean Diameter**: 94.367
- **Standard Deviation of Diameter, by Number**: 53.622
- **Standard Deviation of Volume Dia (Herdan)**: 57.232
- **Coefficient of Variation of Diameter (Number)**: 0.690
- **Coefficient of Var. of Volume Mean Diameter (Herdan)**: 0.318

### Geometric

- **Geometric Number Mean Diameter (Median)**: 63.060
- **Geometric Volume Mean Diameter (Median)**: 168.096
- **Geometric Standard Deviation of Number Diameter**: 1.893
- **Geometric STC Dev of Volume Diameter**: 1.500
## Droplet Distribution Per Run

**DISC NO. 4** / DISC SPEED = 9000 RPM / POTENTIAL = -22.0 KV

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### Statistics Per Run

- **Total Droplet Spot Number in A Run**: 2018.774
- **Number Mean Diameter**: 72.193
- **Volume Mean Diameter (Mugele & Evans)**: 112.440
- **Volume Mean Diameter (Herdan)**: 163.358
- **Sauter Diameter**: 161.325
- **Area Mean Diameter**: 93.937
- **Standard Deviation of Diameter, by Number**: 60.117
- **Standard Deviation of Volume Diameter (Herdan)**: 49.488
- **Coefficient of Variation of Diameter (Number)**: 0.833
- **Coefficient of Variation of Volume Mean Diameter (Herdan)**: 0.270

- **Geometric Number Mean Diameter (Median)**: 52.689
- **Geometric Volume Mean Diameter (Median)**: 174.551
- **Geometric Standard Deviation of Number Diameter**: 2.182
- **Geometric Std Dev of Volume Diameter**: 1.416
**DROPLET DISTRIBUTION PER RUN**

**CISC NO. 4 / DISC SPEED = 9000 RPM / POTENTIAL = 22.0 KV**

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**STATISTICS PER RUN**

- **TOTAL DROPLET SPOT NUMBER IN A RUN**: 1426.262
- **NUMBER MEAN DIAMETER**: 51.002
- **VOLUME MEAN DIAMETER**: 116.169
- **VOLUME MEAN DIAMETER**: 166.942
- **SALTER DIAMETER**: 144.819
- **AREA MEAN DIAMETER**: 104.120
- **STANDARD DEVIATION OF DIAMETER, BY NUMBER**: 50.610
- **STANDARD DEVIATION OF VOLUME DIAM (HERDAN)**: 55.772
- **COEFFICIENT OF VARIATION OF DIAMETER (NUMBER)**: 0.556
- **COEFF. OF VAR. OF VOLUME MEAN DIAMETER (HERDAN)**: 0.334

- **CECMETRIC NUMBER MEAN DIAMETER (MEDIAN)**: 77.411
- **CECMETRIC VOLUME MEAN DIAMETER (MEDIAN)**: 156.608
- **CECMETRIC STANDARD DEVIATION OF NUMBER DIAMETER**: 1.804
- **CECMETRIC STC DEV OF VOLUME DIAMETER**: 1.455
XVII. APPENDIX G. SPRAY DISPERSION
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### Spray Dispersion Characteristics for Sum Droplet Size Distributions

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## SPRAY DISPERSION CHARACTERISTICS FOR RADIAL DROPLET SIZE DISTRIBUTIONS

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### Spray Dispersion Characteristics for Radial Droplet Size Distributions

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