CONTRIBUTIONS TO ELECTROSTATIC DUSTING:
1. APPLICATION OF POLAROGRAPHY TO DUST DEPOSIT EVALUATION,

2. EFFECT OF IONIZED CURRENT INTENSITIES AND EFFECT OF SHIELDING ON DUST DEPOSITION

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Nguyen Tu Ban
1955

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By

Nguyen Tu Ban

AN ABSTRACT

Submitted to the Michigan State University of
Agriculture and Applied Science in partial
fulfillment of the requirements for the
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THESIS

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The ultimate goal of the project on dusting and spraying, of which this study is a part, is the increase in efficiency of deposition and uniformity of coverage of plant surfaces by pesticides. The means to this goal is the utilization of electrostatic field forces.

The specific topics covered by this study are: the application of polarographic analysis to the problem of dust deposit evaluation, the effect of ionized current intensities on dust deposition, and the use of an external electric field to increase dust deposition.

A Sargent Model III, manual type, polarograph was used to measure the copper concentration of hydrated copper sulfate dissolved in an aqueous solution. An electrolyte composed of 0.4 M potassium sulfate and 0.01 percent gelatin, was found suitable for the evaluation of copper sulfate dust.

Copper concentration as low as 1 ppm was readily measured in standard solutions prepared in the laboratory.

The polarographic method of evaluation was then applied to the measurement of copper sulfate dust deposits on soybean leaves after field dusting. Five square inches of leaves -- ten square inches of leaf surface -- were punched into a wash solution containing potassium sulfate. The solution was then brought to the laboratory and analyzed polarographically. The method of evaluation was found satisfactory, both for the field work and for the laboratory experiment.

The field tests on soybean plants showed, in general, no difference in dust deposits between well-exposed leaves and hidden leaves.

Electrostatic dusting appeared better than the conventional method of dusting, although the increase in deposition was not as great as expected.

The effect of current intensities, and the effect of shielding, were studied in the laboratory at sixty percent relative humidity. The shield, made of one-quarter inch hardware screen, was placed parallel to the dust collector disc. A potential of 20 kv was applied to the shield to produce the external electric field. Four dusts were used, and the deposits evaluated by weighing with an analytical balance.

The results showed that for the micronized copper sulfate, the Attaclay and the Attasorb, the dust deposits increased greatly -- as many as ten times -- with increased current intensities up to 150 microamperes. With further increases in the current, the increase in dust deposition was negligible.

Standard copper sulfate followed the same trend as the other dusts. It showed a great increase in deposition around 500 microamperes, and a sharp decrease at 600 microamperes.

Below and up to current intensities of 50 microamperes, shielding improved the deposition of standard copper sulfate and

Attaclay, coarse dusts. Above 50 microamperes, the beneficial effect of shielding disappeared.

Shielding greatly improved the deposition of the micronized copper sulfate, but it decreased the deposition of Attasorb.

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INTRODUCTION

In man's struggle for survival there is the fight against insects, fungi, and weeds, which destroy or hinder the production of his food. The most used weapons in the battle against these foes are sprayers and dusters.

Brodell, Strickler and Phillips (8) report that, in 1952, in the United States alone, about 29 million acres of farmland were sprayed or dusted an average of 2.86 times -- the equivalent of one treatment on 83 million acres -- to combat insects and diseases, at a total cost of about 193 million dollars.

The application of these pesticidal materials at present is inefficient. Bowen (5) estimates that only ten to twenty percent of the dust discharged by dusting machines is actually deposited on the plant surfaces. Sprays are somewhat more efficient. According to Splinter (20), fogs are less efficient. It is apparent then, that any significant increase in the efficiency of deposition of pesticides would mean a considerable saving to the farmer.

Historical Background for the Study

In the belief that crop dusting is basically more sound economically than spraying, Bowen (5), in 1950, initiated the present research project in an effort to improve the efficiency of dust deposition, and the uniformity of coverage on plant surfaces, through the use of electrostatic field forces.

The work accomplished by Bowen, Hebblethwaite, Brazee, and Brittain, and the history of the project are reviewed by Splinter (20).

Splinter (20) discusses the influence of particle size on the effectiveness of an insecticide or a fungicide, the various forces affecting dust deposition, and the results of laboratory and field work. His results were:

1. In general, reduction in particle size of pesticidal dusts increases the effectiveness against insects and fungi. The smaller particles were also found less subject to erosion by rain.

2. An equation was derived with which, it is believed there can be calculated the effect of changes in application rate and in particle size, on the control of plant diseases and insects.

3. Of the forces considered -- gravitational, inertial, thermal, and electrical -- only those due to an electric field, caused by charged particles in an ionizing field, were found to be of potential importance toward effective deposition of fine dust particles.

The General Problem

The ultimate goal of this research project, is the increase of deposition and uniformity of coverage of plant surfaces by pesticides. The means to this goal is the utilization of electrostatic field forces.

The application of electrostatic charging to the deposition of pesticidal dusts, or, in short, electrostatic dusting, gave extremely satisfactory results in the laboratory under controlled conditions. The field work, conducted only on an exploratory scale, has not fulfilled the expectations of the investigators. Extensive field tests have not been planned to date. It is believed that, before further field work is undertaken, it will be worthwhile to make systematic investigations in the laboratory to provide a sounder understanding of this problem.

Among the topics still to be considered are the effect of resistivity of plants, the development of accurate metering devices for dust at very low rates, the development of a fast, reliable and accurate method of evaluating dust deposition on plant surfaces, the effect of the dilution of the dust-air stream from the nozzle by surrounding air on the dust cloud potential, and the superposition of an electric field on the field induced by the dust cloud itself.

The Specific Problem

This study was conducted to investigate specifically: first, the application of polarographic analysis to the problem of dust deposit evaluation; second, the effect of the ionized current intensities on dust deposition; and, third, the use of an auxiliary electric field to increase dust deposition

THE APPLICATION OF POLAROGRAPHY TO THE EVALUATION OF PESTICIDAL DUST DEPOSITS ON PLANT SURFACES

Pest control by dusting depends, in the main, on two factors: coverage, and retention of the pesticidal dust. For effective protection, plant surfaces must be well covered with dust[1], but what this means quantitatively is still unknown. Hebblethwaite (1952) says:

> It is unfortunately a fact that at the present time biologists are unable to give a clear definition of what constitutes "100 percent coverage" and therefore the engineer is in the difficult position of not knowing what his goal is.

The degree of protection is customarily evaluated biologically. This method of evaluation is not always desirable because of the uncertainty of, and the time lapses between, infestations, especially in investigations on the methodology of dusting. The research worker requires a much more rapid method of evaluation, even though it may be less complete. It is only in the final analysis that he will need biological evaluation in the form of field trials. Many workers in the past have resorted to indirect methods of evaluation, either physical or chemical. The chemical evaluation seems to be prevalent (leaf printing to study the problem of distribution,

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[1] In this thesis "dust" will mean pesticidal dust.

ashing and titration for quantitative analysis, and others). Although methods in use may be accurate, a great deal of time is required to perform the evaluation itself.

The following work was done in an attempt to provide the workers in electrostatic dusting at Michigan State University with a fast, but accurate method for the evaluation of dust deposit.

Background for the Study

Definition of Polarography

The polarographic method of chemical analysis, invented by Jaroslav Heyrovsky in Prague about 1920, is based on the unique characteristics of the current-voltage curves obtained from the electrolysis of electroreducible or electrooxidizable substances in a cell at a dropping mercury electrode.

Theoretical Principles

The basic principle upon which polarography depends, is the production of concentration polarization. To illustrate this, and the salient facts pertaining to polarography, consider the electrolysis apparatus shown schematically in Fig. 1. Assume that the electrolytic cell contains a very dilute solution of thallous chloride (say 0.001 M) in a relatively large concentration of potassium chloride

(e.g., 0.1 M). Because oxygen is easily reducible, and its reduction current more or less masks the current of other substances, the cell is provided with a gas delivery tube through which nitrogen or carbon dioxide is passed to remove dissolved air from the solution. C is a short length of platinum wire which serves as the indicator electrode. The other electrode P is a silver-silver chloride electrode whose area is large enough so that it remains depolarized when a small electrolysis current is passed through the solution. An electrode is said to be polarized when it adopts the potential externally impressed upon it with little or no change in the rate of the electrode reaction, i.e., no change in current. The electrode C is of this type. On the other hand, a depolarized electrode is one that retains a constant potential regardless of the magnitude of the current. The silver-silver chloride electrode in 0.1 M potassium chloride behaves in this case very nearly like a depolarized electrode when the current density is small. When an external emf is impressed on this electrode the reaction

$$Ag + Cl^- \rightleftharpoons AgCl + e$$

will proceed either to the right or to the left depending on the polarity of the emf applied. The potential is governed by the concentration of chloride ions, and because this concentration is relatively large, it changes only slightly with changes in current when the current density is small.

If the chloride ion concentration were made very small e.g., 10^{-5} M, then even a relatively small reduction current would increase the chloride ion concentration markedly, and the potential of the silver-silver chloride electrode would change considerably to correspond to the change in chloride concentration <u>at the electrode surface</u>. This phenomenon is commonly called <u>concentration polarization</u>.

Suppose now that an emf is applied to the cell in Fig. 1 in such a direction that the platinum electrode is made negative with respect to the other electrode. The solution is well stirred to minimize the changes in thallous concentration at the surface of the platinum microelectrode. The current-voltage curve obtained is indicated by OAB in Fig. 2. From O to A, the current remains very small. When the potential of the platinum electrode has been made equal to the decomposition potential of the thallous chloride in solution, (point A), a further increase in applied emf causes the reduction of thallous ion at the platinum electrode,

$$Tl^{+} + e = Tl$$

and correspondingly the current increases rapidly. In other words, at point A or beyond, the platinum microelectrode is depolarized by the reduction of thallous ions. With increasingly applied emf, the current increases linearly in accordance with Ohm's law. The slope E/I would give the resistance of the solution in the cell.

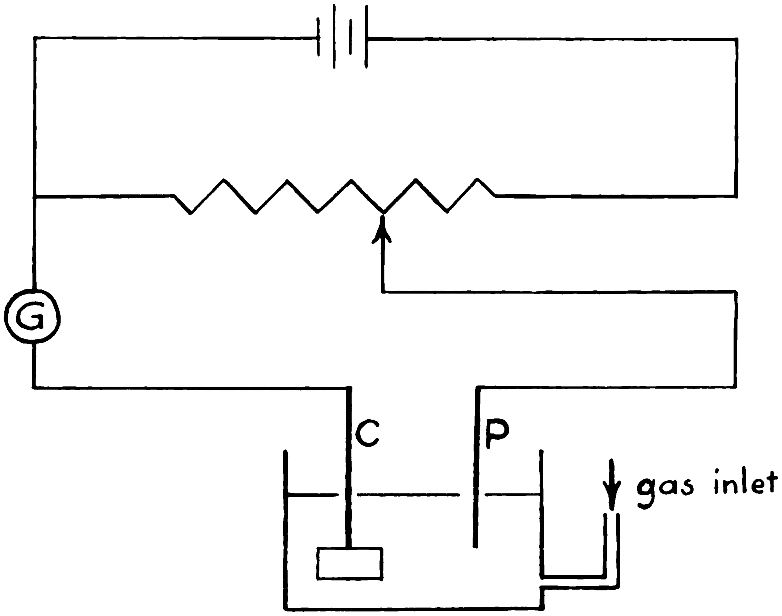

Fig. 1. Schematic diagram of an electrolysis apparatus.

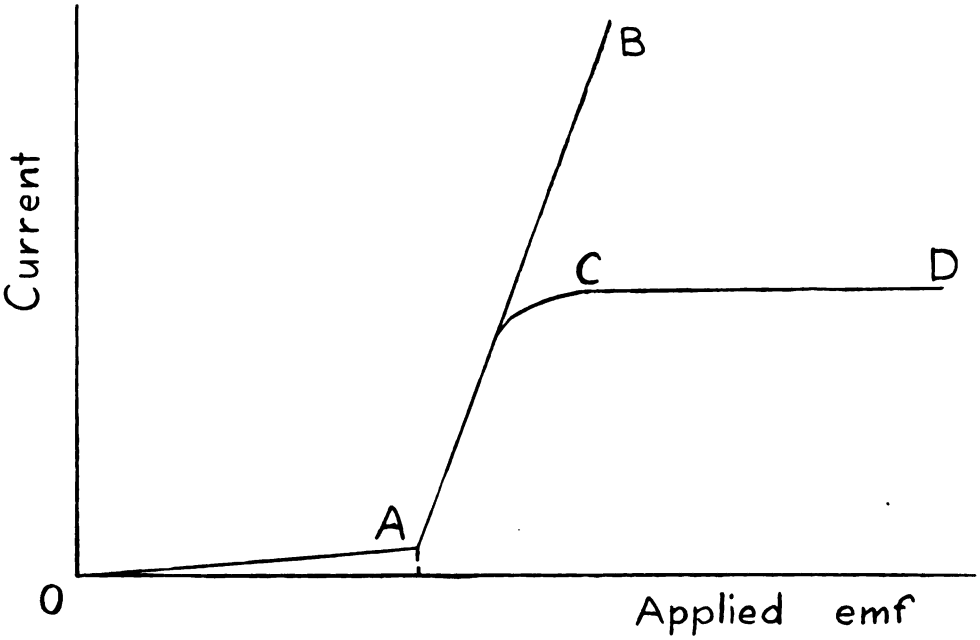

Fig. 2. Current-voltage relationships with (B) polarized and (D) unpolarized electrodes.

Suppose now that the experiment is repeated without stirring the solution. The current, instead of rising indefinitely according to Ohm's law after the decomposition potential is reached, eventually, levels off and becomes constant. This behaviour is illustrated by the curve OACD in Fig. 2.

As the potential of the small electrode is made more and more negative, the concentration of thallous ions at the electrode surface is continually decreased. At point C the thallous ion concentration at the electrode surface is negligibly small compared with that in the bulk of the solution. A further increase in the applied emf from C to D can no longer appreciably decrease the thallous concentration at the electrode surface. The platinum electrode is then in a state of virtually complete concentration polarization, and the current can no longer increase because it is determined by the rate of diffusion of thallous ions from the bulk of the solution to a region of practically zero concentration. This results from the depletion of the thallous ion concentration at the electrode surface by the electrode reaction.

The region CD is called a diffusion current region. Because the rate of diffusion is proportional to the difference in concentration in the two regions between which diffusion occurs, the diffusion current is proportional to the concentration of thallous ions in the bulk of the solution. This proportionality is the basis for quantitative determinations by polarographic analysis.

In the above experiments, a relatively large concentration of non-reducible electrolyte (potassium chloride) was added to the solution in order to minimize the electrical migration of thallous ions. A non-reducible electrolyte added to an electrolysis solution in polarography is called a "supporting electrolyte". The rate of electrical migration of thallous ions depends on their relative concentration as compared with the concentration of potassium chloride, and on the transference numbers of thallous and potassium ions.

A transference number measures the fraction of total current carried by a given ion in a solution (17).

When the concentration of the supporting electrolyte is much greater than that of thallous chloride, the transference of thallous ions is reduced to practically zero, and the current through the solution is carried almost entirely by the ions of the supporting electrolyte. The transfer of thallous ions to the cathode is then made entirely by diffusion, and the diffusion current is said to be diffusion controlled. If the electrical transference is greater than the diffusion current. The difference between the two is called the migration current (16).

Because, in many ways, the polarographic method of analysis bears resemblance to the electrolytic method, some of the fundamental differences between the two methods are tabulated as follows:

Method / Parameters	Polarographic	Electrolytic
Electrodes (for electroreducible substances only)	Cathode: Dropping mercury electrode or rotated microelectrode. Anode: Mercury pool or saturated calomel electrode (reference electrode).	Cathode and Anode: Platinum or mercury electrode
Variables measured	Currents measured with increasing applied emf.	Current or voltage constant
Concentration range	Low limit 10^{-6} M.	All concentrations
Depletion of electroreducible substance	Practically unaltered.	Complete
Duration	Short, usually a few minutes.	Until completion of electrochemical reaction.
Current conduction between electrodes	By migration of supporting electrolyte ions through solution, and by diffusion only to the electrode.	Migration and diffusion

In the interests of simplicity and clarity, the following discussion includes only electroreducible substances, thus the repetition of the two terms "electroreducible" and "electrooxidizable" will be avoided.

Polarograph Circuit

The electrical circuit used is very similar to the one for electrolysis, a schematic diagram of which is shown in Fig. 3. For electroreduction an increasing negative emf is applied between the electrodes by varying the resistance R. The current for each applied emf is measured with a galvanometer G. The plot of current against voltage results in a polarogram, Fig. 4.

Polarogram

The limiting current (i) is the total steady current measured (Fig. 4). The limiting current is reached when the reducible substance is reduced as rapidly as it reaches the electrode surface and its concentration at the electrode surface remains constant at a value that is negligibly small compared to the concentration in the body of the solution. Under these conditions, the current is independent, within certain limits, of the applied emf and is governed wholly by the rate of supply of the reducible substance to the electrode surface from the surrounding solution.

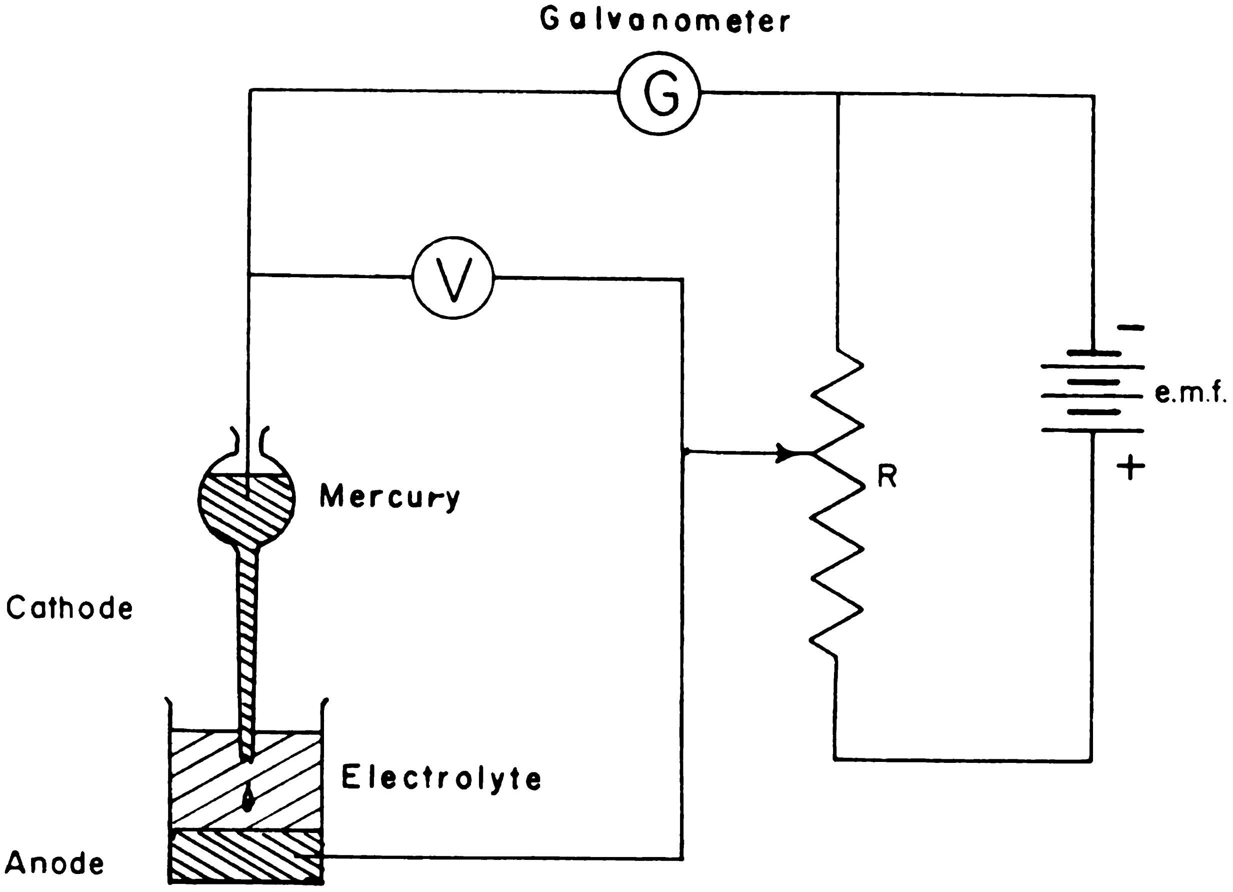

Fig. 3. Schematic diagram of polarographic circuit.

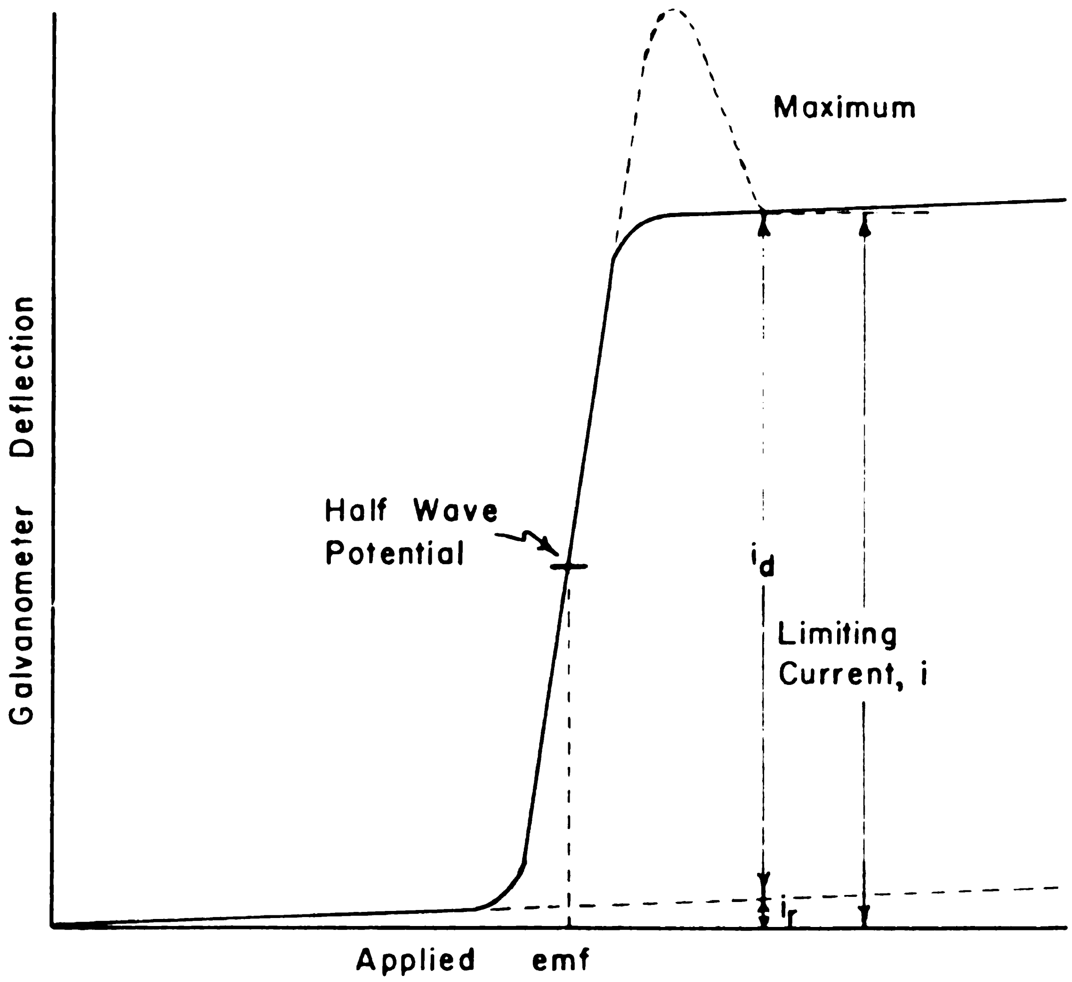

Fig. 4. A typical polarogram.

Of the many factors influencing this current, four of the most important are:

1. The residual current (i_r), usually very small and approximately proportional to the applied voltage, caused by traces of electroreducible impurities;
2. The "maximum", a transitory and erratic current, the origin of which is not completely understood, but which is eliminated by the introduction of a surface-active material or charged colloids, e.g., gelatin;
3. The migration current due to electrical migration of the reducible ions which is eliminated by the addition of an indifferent or supporting electrolyte in a concentration of at least 50 times that of the reacting material; (see page 11)
4. The diffusion current (i_d) which indicates the concentration of the material being reduced.

   $$i_d = i - i_r$$

   The diffusion current depends on temperature, viscosity, the ionic strength of the solution, and the characteristics of the polarizable electrode. The influence of these factors can be seen in the Ilkovic equation, derived for the dropping mercury electrode for constant temperature:

$$i_d = 607\ n\ D^{1/2}\ C\ m^{2/3}\ t^{1/6}$$

where i_d is the average current in microamperes during the life of a drop of mercury, n the number of Faradays, D the diffusion coefficient of the reducible or oxidizable substance in square centimeters per second, C its concentration in terms of millimoles per liter, m the rate of flow of mercury from the dropping electrode capillary in milligrams per second, and t the drop time in seconds (16).

This equation predicts a linear relation between the diffusion current and the concentration, the most important relation in practical polarography.

The half-wave potential is characteristic of an electro-reducible substance in a known supporting electrolyte, and serves as the basis for qualitative identification of the substance.

To reiterate, quantitative polarography is based on the complete concentration polarization (see page 10) or the depletion of the concentration of the electro-reducible substance at the electrode surface by the electrode reaction which results in a limiting current over a range of potential.

For a detailed study on polarography, the reader is referred to the two volumes "Polarography" by Kolthoff and Lingane (16). Excellent bibliographies of polarographic literature may be found in the following references:

1. "Bibliography of Polarographic Literature," 1922-1945, E. H. Sargent and Co., Chicago, 1950.

2. "Bibliography of the Dropping Mercury Electrode," Leeds and Northrup Co., Philadelphia, 1950.

Equipment and Procedure

A Sargent Model III polarograph, of the manual type, was used. The voltages and currents were read and recorded. These values were then plotted to obtain the polarogram. The H-type cells used were of a design (Fig. 5) suggested by Dr. Andrew Timnick of the Department of Chemistry, Michigan State University. Saturated calomel electrodes served as reference electrodes. The cathodes were of the dropping mercury electrode type (Fig. 6). This type consists essentially of a capillary glass tube supplied with mercury from a reservoir. The apparatus was arranged as shown in Figure 6.

Laboratory Investigations

Hydrated copper sulfate[2] was selected as a dusting material to be used both for the laboratory and the field tests, because of its solubility in water, and because copper is a common element in dusting materials.

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[2] See Appendix A for specifications of the dust.

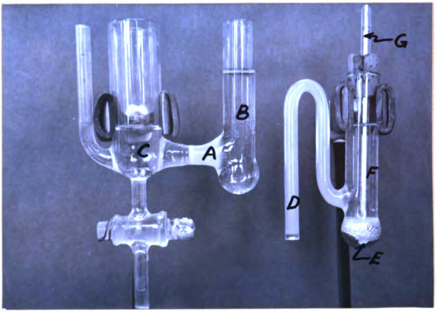


Fig. 5

Left - H type cell

- A - Agar plug
- B - Saturated KCl and calomel solution
- C - Solution for analysis

Right - Saturated calomel electrode

- D - Agar bridge
- E - Mercury pool
- F - Saturated KCl and calomel solution
- G - Electrode filled with mercury

In preparing the saturated calomel electrode, care must be taken that the platinum loop at the end of this electrode is well placed in the mercury pool and that it does not touch the calomel solution.

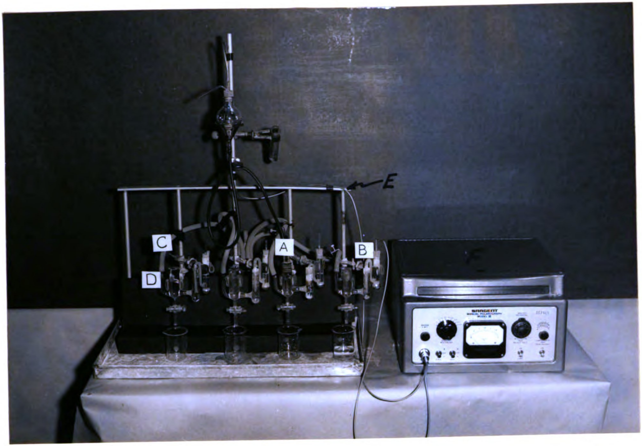


Fig. 6

Polarograph Assembly:

A - Mercury dropping electrode (cathode)
B - Saturated calomel electrode (anode)
C - Nitrogen inlet

D - H-type cell
E - Multiple-cell mount
F - Polarograph

The supporting electrolyte found most suitable for this dust, was potassium sulfate at a concentration of 0.4 M.

Gelatin, at a concentration of 0.01 percent, was very effective as a "maximum" suppressor. Empirical calibration curves were then constructed by analyzing standard solutions of known concentrations.

Calibration Curves

Because the calibration curves were constructed strictly on an empirical basis, the following conditions were maintained constant at all times, during the analysis for calibration purposes and afterward during the evaluation of actual test solutions:

1. Composition of supporting electrolyte,
2. Characteristics of the dropping electrode, i.e., constant m and t values,
3. Concentration of maximum suppressor.

A standard solution of copper sulfate ($Cu\ SO_4$, $5H_2O$) was prepared by dissolving 0.3928 gm of copper sulfate in water. Enough water was then added to increase the volume to 100 ml. The solution contained one milligram of metallic copper per milliliter of solution or 1000 ppm. Subsequent known concentrations were obtained from this standard solution by dilution.

To eliminate the effect of the migration current, 0.4 M potassium sulfate solution was used as the supporting electrolyte. Gelatin at a concentration of 0.01 percent was used as the maximum suppressor.

A 25-ml standard solution containing 10 ppm copper was analyzed, and its polarogram plotted (Fig. 7). This plotting was a preliminary step in determining the half-wave potential of copper in 0.4 M potassium sulfate solution, and also in finding the potential at which the limiting current became steady. From this polarogram, the value of -0.4 volts was selected as the applied emf for routine analyses.

For routine analysis the complete plotting of the polarogram is unnecessary. During the evaluation, only the concentration of the reduced substance is measured, it being the only variable in the Ilkovic equation, other factors being held constant.

Subsequent standard concentrations were then analyzed by bringing the applied emf immediately to -0.4 volts and recording the galvanometer deflections, that is, high and low values from which the average deflection was computed. The emf was next brought to zero and the galvanometer deflections were again read and recorded. The second average value was subtracted from the first one, and the result used in the plotting of the calibration curve. This was done to minimize the error due to the drifting of the galvanometer zero reading.

Calibration curves (Fig. 8) were constructed using the data shown in Table I.

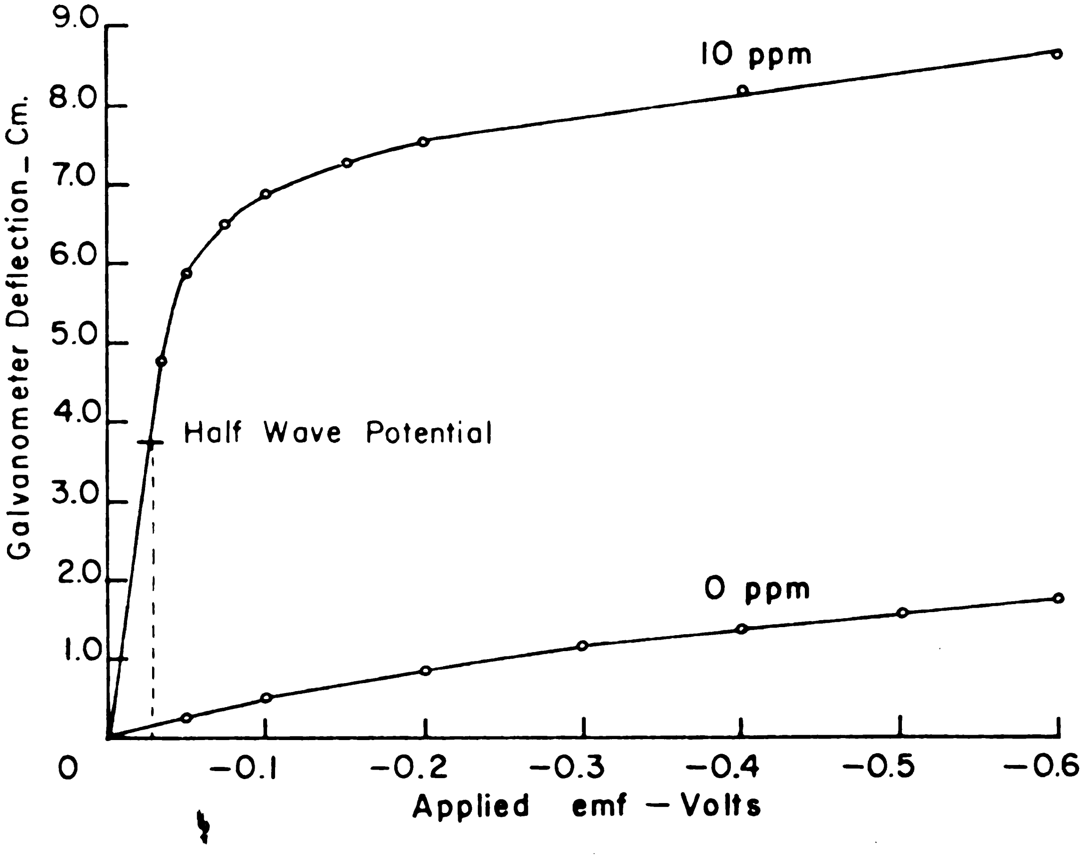


Fig. 7. Polarogram of copper sulfate in 0.4 M potassium sulfate and 0.01 percent gelatin.

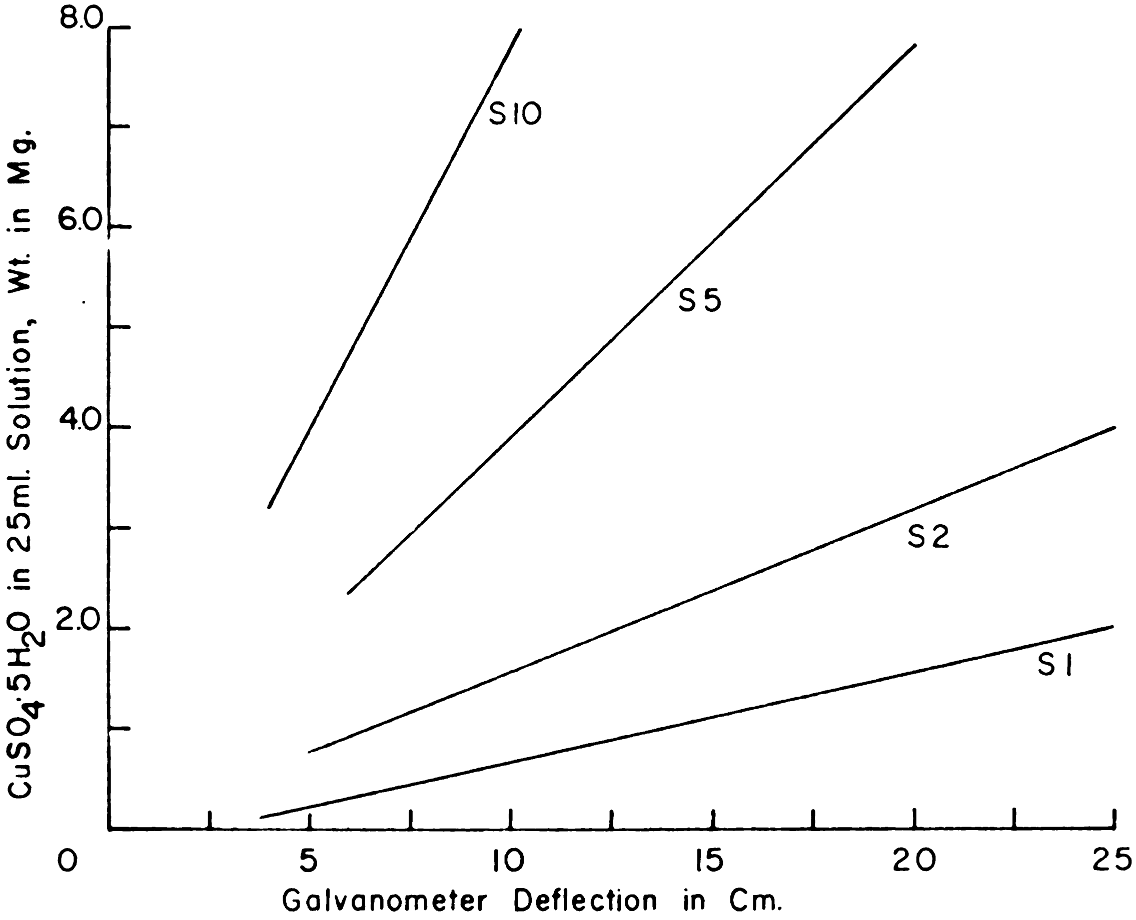


Fig. 8. Calibration curves of copper sulfate in 0.4 M potassium sulfate and 0.01 percent gelatin. Galvanometer reading at -0.4 volt.

TABLE I

POLAROGRAPH CALIBRATION DATA OF COPPER SULFATE IN 0.4 M K_2SO_4 AND 0.01 PERCENT GELATIN

Average galvanometer deflections in cm. measured at -0.4 volts

Galvanometer Sensitivity Setting	Copper Concentration in Parts Per Million													
	0	1	2.5	5	10	20	25	30	40	50	75	100	125	150
1	2.51 2.53 2.10	3.55 3.50 3.08 3.04 3.20 3.25	5.27 5.30 5.49	7.78 7.85 7.70	13.52 13.50 13.20 13.70	25.03 24.75 25.08								
Average	2.38	3.27	5.35	7.78	13.48	24.95								
Equivalent in weight of $CuSO_4$, $5H_2O$* dust in 25 ml. solution, micrograms	0	98.2	245.5	491.0	982.0	1964.0	2455.0	2946.0	3928.0	4910.0	7365.0	9820.0	12275.0	14730.0
2	1.07 1.28 1.02				6.40 6.43 6.83	12.05 12.17 12.62		18.75 18.10 18.47	24.38 24.87 24.35					
Average	1.12				6.55	12.28		18.44	24.53					
5	0.45						6.12 6.35			12.45 12.57	18.62 19.35	26.10 25.35 26.05		
Average	0.45						6.24			12.51	18.99	25.83		
10	0.27						3.07			6.18 6.22	9.42 9.57	12.60 12.83	16.21 16.10	19.90
Average	0.27						3.07			6.20	9.49	12.72	16.16	19.90

* Conversion factor: 1 gm Cu = 3.928 gm $CuSO_4$, $5H_2O$; 1 ppm Cu = 1.0 mg Cu per 1000 ml solution.

Instead of plotting galvanometer deflection as a function of concentration, the weight of hydrated copper sulfate was computed from the concentration in parts per million and plotted as a function of the galvanometer deflection. In this way, one reading of the calibration chart gave directly the amount of hydrated copper sulfate in 25 ml of solution.

It should be noted that the galvanometer deflections recorded measured both the diffusion current and the residual current. Evaluation of the diffusion current alone was not necessary.

Results

Copper concentration as low as one part per million was readily detected. This sensitivity could still be improved if rigorous temperature control was observed. Kolthoff and Lingane (16) stated that the lower limit of polarographic detection was in the neighborhood of 10^{-6} M. This is approximately equivalent to 0.064 parts per million copper concentration, or 0.25 milligrams per liter of solution of the hydrated copper sulfate used in this investigation.

Laboratory Dust Deposit Evaluation

Brittain utilized the polarographic method successfully in his laboratory work on plant-leaf surfaces. The surfaces were dusted with copper sulfate. The dust deposits were then

carefully washed off by shaking the leaves in closed Mason jars containing 24.5 ml of potassium sulfate solution, which upon addition of 0.5 ml of gelatin solution, had a molarity of 0.4. These solutions were then analyzed polarographically. For details, the reader is referred to Brittain's thesis (7).

Scope of the Polarographic Method

The polarographic method of analysis as applied to the quantification of dust deposit is not restricted to copper measurement alone. The method can be applied to any other dusting materials, organic or inorganic, provided that a suitable solvent and a good supporting electrolyte can be found for each material, and provided that the substances measured contain at least one element that is either reducible or oxidizable.

FIELD TESTS TO STUDY THE FEASIBILITY OF THE POLAROGRAPHIC METHOD OF DUST EVALUATION

When the method of dust evaluation with the polarograph was finally worked out during the latter part of the summer of 1954, it was decided to test its feasibility in the actual evaluation of leaf samples collected in field tests.

The field tests were carried out with this specific purpose in mind and also to study the following:

1. To investigate the efficiency of electrostatic dusting in depositing dust in "hidden" parts of plants.
2. To compare the deposition of conventional and electrostatic dusting as a function of the rate of application of dust.

Description of Equipment

Dusting Equipment

The field duster used was an adaptation of a Niagara "Even Flow" Model AA machine. It was an eight-nozzle duster equipped with a Niagara Evenfeed dust metering unit. The power to drive the duster unit was supplied by a 7 H.P. Novo one-cylinder gasoline engine (Fig. 9).

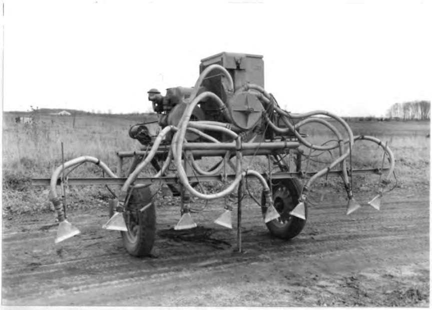


Fig. 9. Rear view of experimental duster.

Fig. 10. Side view of experimental duster showing charging equipment.

The charging apparatus consisted principally of a high voltage tripler circuit connected to a 300-volt dynamotor powered by a six-volt battery (Fig. 10).

A more complete description of the experimental duster and the electrical circuit used will be found in Hebblethwaite's thesis (12).

Dust Evaluation Equipment

The apparatus used is as described on page 18. The wash solution for dissolving the hydrated copper sulfate dust deposited on leaf surfaces was prepared in large quantity by dissolving 71.094 grams of potassium sulfate (M. W. 174.25) in distilled water and making up the final volume to exactly one liter. Half-pint Mason jars were filled with 24.5 ml of this wash solution and taken out to the test plot. A multiple-cell mount was constructed to allow the simultaneous analysis of more than one solution (Fig. 6).

For sampling leaves, a leaf punch was built according to the specifications of Smith and Little (19). It was patterned after an ordinary paper punch. The punched area measured one square inch.

Plot Design and Procedure

A randomized block design was used to set up test plots. The dusting was carried out on soybeans, planted in rows, 24 inches wide and spaced 85 inches center to center. Soybeans were chosen because they were the only crop available at the time (September 1954).

The dust used was standard hydrated copper sulfate. Its size analysis will be found in Appendix A. Three rates of application were used. These rates were determined by directly weighing the actual amount of dust output for each setting of the duster feed cut-off. The rates of application were:

1. Low rate, 27.2 lbs. per acre,
2. Medium rate, 42.3 lbs. per acre,
3. High rate, 68.2 lbs. per acre.

Only four central nozzles of the duster were connected for electrostatic charging. The charging current was set at 75 microamperes for each nozzle.

The actual experimental layout of the plots is shown in Fig. 11. A code for the various plot symbols was set up as follows:

1. The first letter referred to whether the dust was charged or uncharged (C and U respectively),
2. The second letter referred to the rate of application (high H, medium M, or low L).

In each case the treated rows were separated by untreated rows to avoid contamination. Each plot measured fourteen feet wide, and fifty feet long.

To assure uniformity and consistency for each treatment, all the plots marked for the same treatment were dusted at

Row Section	1	2	3	4	5	6	7
I	CL		UL		UH		UM
II	UL		CM		CL		CM
III	UM		UM		CH		CL
IV	CH		CL		CH		UH
V	UH		CM		UH		UM
VI	UL		CH		UM		CM

Fig. 11. Plot design for field tests on soybeans.

CL = Charged, low rate

CM = Charged, medium rate

CH = Charged, high rate

UL = Uncharged, low rate

UM = Uncharged, medium rate

UH = Uncharged, high rate

Low rate = 27.2 lbs. per acre

Medium rate = 42.3 lbs. per acre

High rate = 68.2 lbs. per acre

one time. The samples were then gathered before the next treatment was applied. In this manner, the duster was driven more than once over each plot, but the immediate sampling after each treatment eliminated the knocking-off of dust from the leaf surfaces.

The sampling was done by laying a fifty-foot steel tape along the row and gathering leaf samples at the row center, at the 20th and at the 40th foot mark (Fig. 12). Two types of leaves were collected, the top leaf, well exposed to the dust stream, and the lower "hidden" leaf. For each sample, five square inches of leaf surface -- counting one side only -- were punched into each Mason jar containing 24.5 ml of wash solution. The jar was closed tightly and shaken immediately to wash the copper dust deposit off the leaves. Shaking for one minute was found adequate by Brittain (7) to dissolve all the copper dust deposited. Blank solutions were also included. These solutions were taken back to the laboratory and evaluated polarographically for dust content.

The relative humidity during the whole test varied between 45 percent and 63 percent. The wind velocity measured with a hot-wire anemometer was between 200 and 750 fpm. Most of the time its direction was at a right angle to the forward direction of the duster. The dusting was carried out only in one direction. At the end of each test row, instead of going back in the opposite direction, the duster was driven

Sampling Technique

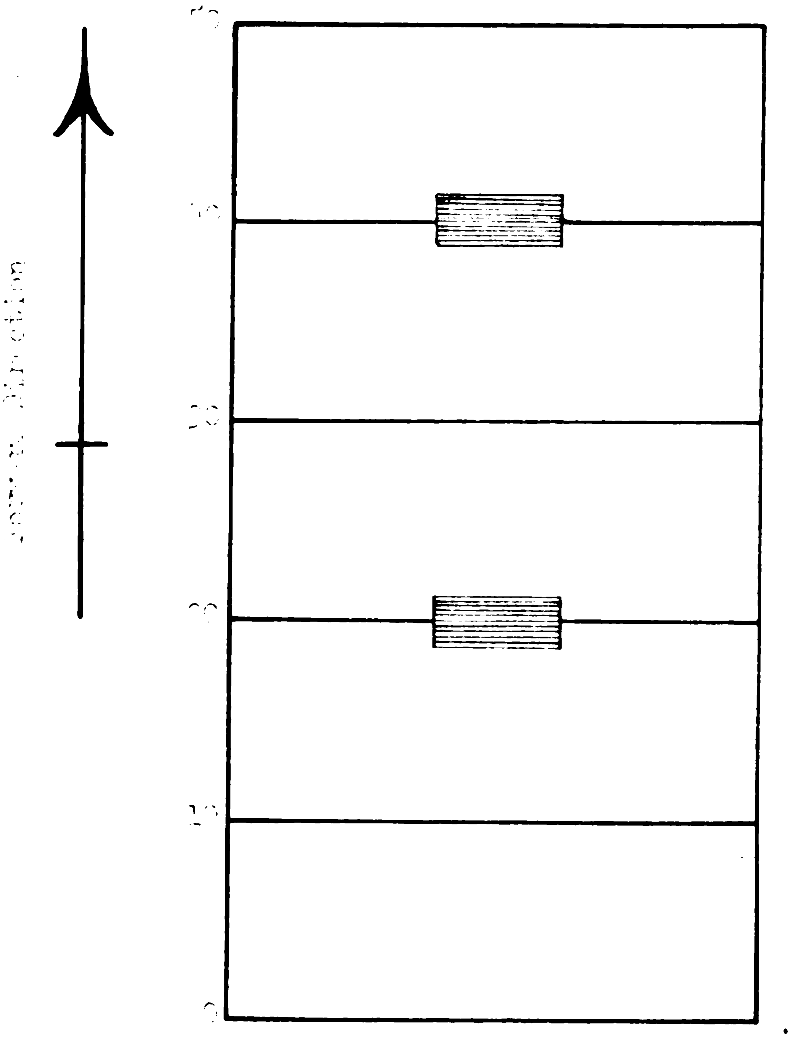


Figure **12.**

Sampling was done at the row center and at the 20th and 40th foot mark.

Top - the leaves sampled were on top and well exposed.

Bottom - the leaves sampled were well hidden and close to the ground.

back to the end of another row and the test run in the same direction as on the first row.

For the routine evaluation of the solutions the following steps were taken in the laboratory:

1. 0.5 ml of a one percent gelatin was added to the Mason jar; the solution then had a final volume of 25 ml, containing 0.4 M potassium sulfate, 0.01 percent gelatin, and copper at a concentration to be found upon analysis;

2. About 20 ml of this solution was introduced into the H-type cell;

3. Commercial oil-pumped nitrogen was bubbled through for about 10 minutes to displace dissolved air;

4. An emf of -0.4 volts was applied, the low and high galvanometer deflections were recorded, and the average value computed;

5. The emf was brought to zero, the new high and low galvanometer deflections recorded and the average deflection computed. This value was subtracted from the average value obtained in step 4, and the resulting value used to find the amount of hydrated copper sulfate in solution from the calibration chart (Fig. 8).

With the aid of the multiple-cell arrangement (Fig. 6) the operator was able to work on three samples simultaneously, and thus cut down the time required for each analysis from 15 minutes to 6 minutes.

Discussion of Results

Merit of the Polarographic Method of Analysis

Hydrated copper sulfate at a concentration as low as 0.10 mg in 25 ml of solution was measured polarographically. During the evaluation the blank solutions from the test plot were analyzed and no trace of copper was detected. Spot checks of the three cells at one time or another with blank solutions made up in the laboratory, likewise showed no trace of copper. It was felt that the polarographic method was consistent, and that the results obtained from the analyses were reliable. This was rather gratifying because it was the first time in the history of the electrostatic dusting project that a dependable evaluation method provided readily available data from the actual field tests.

Dust Deposits Analysis

The results of the tests are shown in Table X in the Appendix B. Figure 13 and Table II show the average values of the deposits resulting from different treatments. For the charged dust, the deposits appear to bear a linear relationship to the rate of application (curves B and D). This is not so with the uncharged dust; the increase in deposits between the low and the medium rates was definitely less than the increase in deposits between the medium and the high rates of dust application. A closer study of the data reveals that for the medium rate of application with uncharged dust, two out of eight samples collected from the top leaves had no dust deposits, and for the "hidden" leaves, four out of eight samples collected had no dust deposits. This situation did not exist with the charged dust. It appeared then that the charged dust gave a more uniform coverage to plant surfaces than did the uncharged dust. The variations between deposits for each treatment, at different dust rates, are shown in Fig. 14. The middle curves represent the average values of dust deposits on ten square inches of leaf surface -- counting both sides. The lower curves represent the lower; and the upper curve, the upper limits of the deposits.

Comparison of Top Leaf and Hidden Leaf Deposits

It appeared that, in general, the "hidden" leaves received slightly more dust than the top leaves. This was not expected. A closer study of the duster nozzle position yielded the following observations: the nozzles had been adjusted to project the dust stream straight down, and, therefore,the blast did not help dust deposition on top leaves, but the "hidden" leaves may have received some beneficial effect from the dust reflected from the ground.

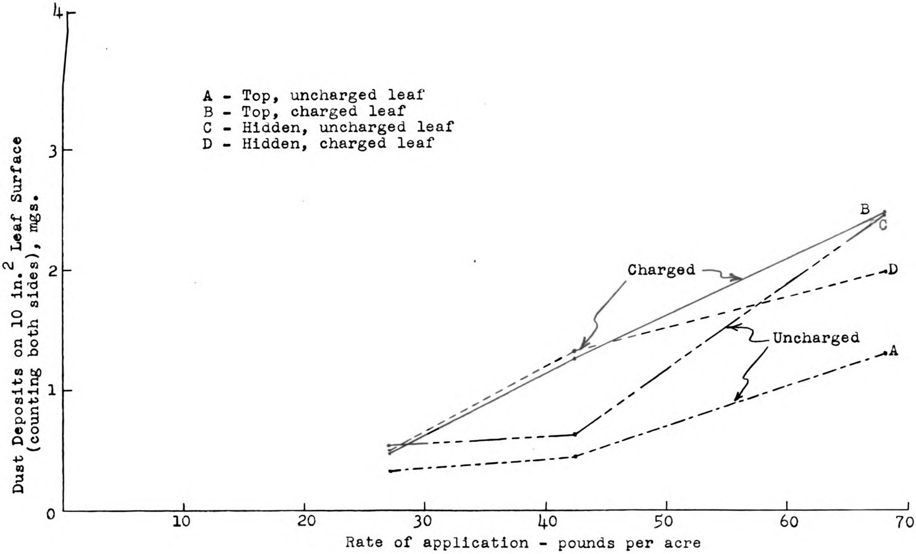


Fig. 13. Dust deposits on soybeans as a function of rates of application. Results are averages from eight replications.

TABLE II

AVERAGE VALUES OF DUST DEPOSITS FROM FIELD TESTS ON SOYBEAN PLANTS

(Weight in milligrams)

Rate Lbs. per acre	Top Leaves		Hidden Leaves	
	Uncharged	Charged	Uncharged	Charged
27.2	0.336	0.469	0.535	0.480
42.3	0.436	1.251	0.633	1.314
68.2	1.298	2.468	2.440	1.983

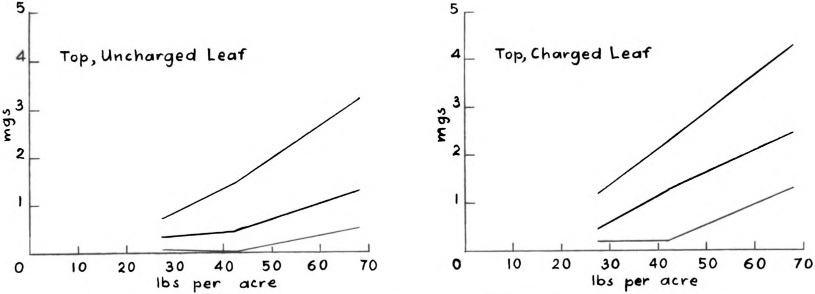
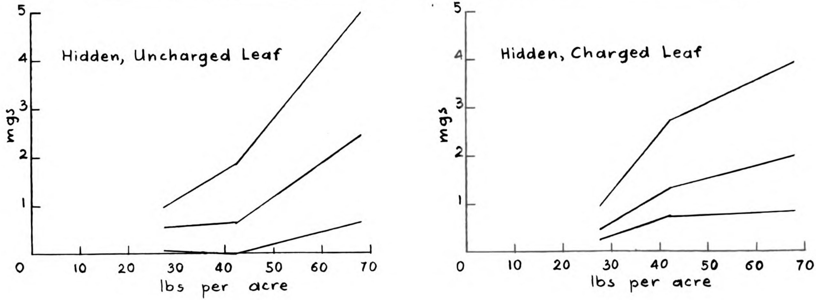


Fig. 14. Dust deposit variation. Top curves and bottom curves represent upper and lower limits respectively.



Analysis of Variance

The analysis of variance of the data (Table III) indicates a significant difference, at the one percent level, between rates of application. The difference between charged and uncharged dust is also significant at the one percent level. There is an interaction between the position of the leaves and the treatment of the dust which is significant at the five percent level. The difference in deposits on well-exposed leaves and on "hidden" ones is not significant.

Dust Deposition Efficiency

In computing the dust deposition efficiency of the field tests the following assumptions were made:

1. The total leaf area (both sides) per acre of soybean plants was estimated to be six acres, on the basis of Stanley's work on leaf area (21), and on the maturity of the plants at the time of dusting.

2. The average deposits shown in Table II are typical for the area dusted at the specified rate of dust application. Furthermore, the deposits for top leaves and for hidden leaves are added and the average values used in the computation.

TABLE III

ANALYSIS OF VARIANCE OF DUST DEPOSITS ON SOYBEAN PLANTS

Source	D.F.	S.S	M.S.	F
Total	95	102.5492		
Rate	2	43.0067	21.5034	37.99**
Treatment	1	3.4960	3.4960	6.18**
Position	1	0.8512	0.8512	1.50
R x T	2	2.0100	1.0050	1.78
R x P	2	0.2387	0.1194	0.21
T x P	1	2.5221	2.5221	4.46*
R x T x P	2	2.8787	1.4394	2.54
Error	84	47.5458	0.5660	

** - Significant at the 1 percent level
* - Significant at the 5 percent level

Sample calculation:

Average dust deposit on ten square inches of leaf area:

0.436 mg

Total dust deposit on six acres of leaf area:

$$\frac{6 \text{ acres} \times 43{,}560 \text{ ft}^2 \times 144 \text{ in}^2 \times 0.436 \text{ mg} \times 1 \text{ gm} \times 1 \text{ lb}}{1 \text{ acre} \times 10 \text{ in}^2 \times 1 \text{ ft}^2 \times 1000 \text{ mg} \times 453.6 \text{ gm}}$$

$$= 3.617 \text{ lbs}$$

Efficiency: $\frac{3.617}{27.2} \times 100 = 13.3\%$

The different efficiencies are summarized in Table IV. It is believed that the values for the uncharged dust, i.e., for the conventional dusting practice, are fairly representative of present-day performance of dusting machines. However, these values should not be accepted at face value, but should be taken only as a springboard for more extensive and intensive studies of duster performance.

TABLE IV

DUST DEPOSITION EFFICIENCY IN SOYBEAN TESTS

Rate (Lbs. per acre)	Uncharged Dust		Charged Dust	
	Average Deposit on 10 sq. in. of leaf area (wt. in mg.)	Efficiency (percent)	Average Deposit on 10 sq. in. of leaf area (wt. in mg.)	Efficiency (percent)
27.2	0.436	13.3	0.474	14.5
42.3	0.534	10.5	1.283	25.2
68.2	1.869	22.7	2.225	27.1

THE EFFECT OF THE IONIZED CURRENT INTENSITIES AND THE EFFECT OF SHIELDING[1] ON DUST DEPOSITION

The effect of current intensities on dust deposition was first investigated by Hebblethwaite (12). His results were of a qualitative nature, i.e., the dust deposits were measured in light meter indices and no quantification of the amount of dust deposited was attempted. The present study was made, first to verify Hebblethwaite's results, and second to evaluate the deposits quantitatively.

At the same time this study was conducted, another series of tests was run to find out the effect of superimposing an external electric field on the field induced by the dust cloud in order to drive the dust to the dust collector and thereby precipitate it. The external electric field was generated by impressing a high voltage on a "shield" placed close to the brass disc. It was thought that the external electric field, with the same sign as the field induced by the dust cloud, would drive the charged dust particles away from the shield and on to the dust collector.

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[1] "Shielding" refers to the use of an external electrical field force produced by an electric shield.

Experimental Equipment and Procedure

Laboratory Dust Chambers

A brief discussion of the laboratory dust chambers is given herewith. A more complete description of the dusting laboratory has been given by Brittain (7).

The test chambers were composed of two compartments, a dust feed chamber and a dusting chamber.

The dust feed chamber. The dust feed chamber housed the dust metering mechanism, the blower, and a set of wet and dry-bulb thermometers. The blower, from an old hammermill, replaced the conventional Niagara duster fan in the attempt to reduce the amount of dust collected on the fan blades.

The blower was driven by a three-horsepower, variable-speed motor. The motor speed was adjusted to 2500 revolutions per minute for all tests.

The dust feed chamber was air tight, except for an eight-inch intake where air was drawn into the chamber by the sucking action of the blower (Fig. 15). The air intake was connected to a ducting system equipped with a steam injector with which the relative humidity in both test chambers could be controlled. The duct was arranged so that air could be taken in from either inside or outside the room.

The wet and dry bulb was of a design similar to the constant-level wet-bulb system described by Henderson (13).

Fig. 15

Dust feed chamber.

A - Air inlet

B - Blower

C - Dust hopper

D - Conveyor belt

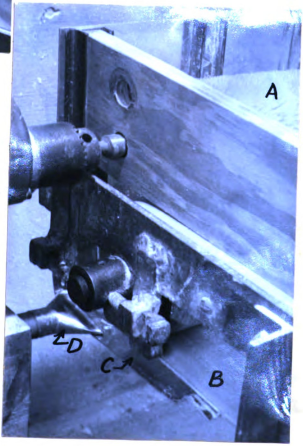

Fig. 16

Feed end of dust feed mechanism.

A - Cleaning brush

B - Conveyor belt

C - Dust chute

D - Air nozzle

The dust feed mechanism. The dust feed mechanism consisted essentially of a horizontal conveyor belt moving at a uniform speed of 0.890 feet per minute (Fig. 16). For each run, ten grams of dust were distributed evenly lengthwise on ten inches of the conveyor belt. At the feed end of the belt, a rotating brush swept the dust into the chute, breaking the clumps into a uniform cloud of dust. The sheet-metal chute was placed at a slight angle, inclined toward the inlet of the blower fan. At the other end of the chute, a small air stream coming from a compressor operating at nineteen pounds per square inch was directed parallel to the bottom of the chute, in order to prevent the dust from depositing on the chute. This arrangement was found rather effective in preventing the dust from clogging the chute, as mentioned by Brittain (7).

The dusting chamber. The dust stream coming from the dust fan was blown into the dusting chamber through a connecting tube. The charging nozzle was mounted on the end of the tube protruding into the dusting chamber. The arrangement for collecting dust is shown in Figure 17. The dust collectors were three-inch discs (Fig. 18) cut from brass shim stock, 0.010 inch thick. The disc was placed 42 inches from the nozzle, parallel to the dust stream to minimize the effect of inertial force on dust deposition. An exhaust fan at the

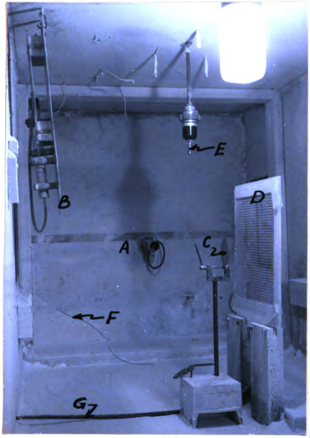

Fig. 17

Inside of dusting chamber.

A - Protruding nozzle

B - Wet and dry-bulb thermometers

C - Dust collector disc

D - Shield

E - Air sampling device

F - Ground lead to disc

G - High voltage lead to shield

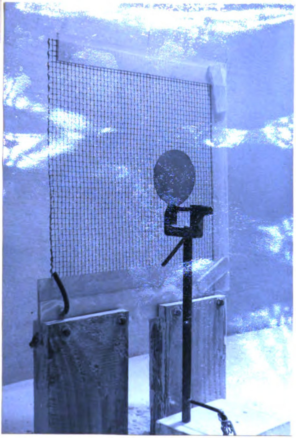

Fig. 18

Dust collector disc and electric shield.

far end of the dusting box removed the excess dust. The baffle of this exhaust fan was adjusted so that the pressure inside the dusting chamber was one-fourth inch of water below the atmospheric pressure. This slight vacuum was maintained to keep the dust from leaking into the laboratory.

Charging Nozzle

The charging nozzle used is shown in Fig. 19. This double-support type was used in preference to the single support (Fig. 19) type because of its higher break-down voltage, and higher charging current (Table V).

Fig. 20 shows the inside construction of a single-support type charging nozzle.

Electrical Circuit

A tripler circuit provided the high voltage. The maximum output of this high-voltage power supply was 30 kv and 1 ma. The input to the tripler circuit was a 300-volt, D.C. power supply. A rheostat on this power supply controlled the output of the high-voltage tripler circuit. For each test, both voltage and current were measured, and the current was kept constant, as close to the desired value as possible. The voltage was measured across the charging nozzle with a Simpson 269 meter, equipped with a special probe (Fig. 21). An RCA vacuum tube microammeter connected on the ground side of the charging nozzle indicated the current.

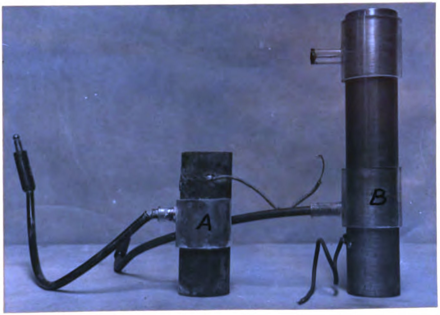

Fig. 19. Two types of charging nozzle.

A - Single-support type

B - Double-support type

TABLE V

CHARGING NOZZLE PERFORMANCE

Type	Voltage Input to Tripler Circuit (volts)	Voltage Output from Tripler Circuit (kilovolts)	Output Current (microamperes)
Double-Support Nozzle	180	6.2	0
	200	7.9	2
	220	8.6	23
	240	9.7	73
	260	11.2	168
	280	12.8	290
	300	14.0	430
	310	14.5	490
	320	15.1	580
	---	15.4 Breakdown	635
Single-Support Nozzle	180	6.5	0
	200	7.4	3
	220	9.4	17
	240	11.3	61
	260	11.8	135
	280	12.6	265
	290	13.0	315
	300	13.1 Breakdown	400

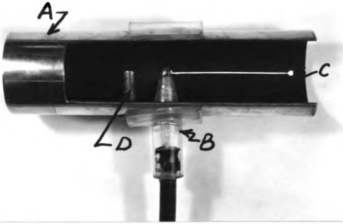

Fig. 20. Inside construction of a single-support type charging nozzle.

A - Main tube of charging nozzle

B - Plexiglas insulator

C - Charging needle

D - Post to deflect air stream

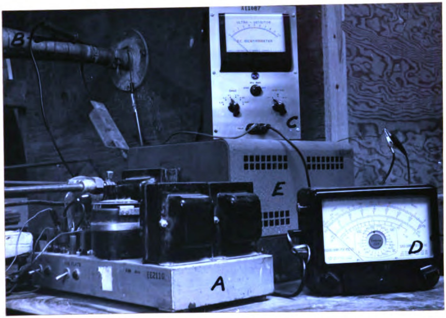

Fig. 21. Nozzle charging apparatus.

A - 300-volt D.C. supply

B - High-voltage probe

C - RCA microammeter

D - Simpson 269 meter

E - Tripler-circuit power supply

Electric Shield

The shield used to superimpose an external electric field on the field induced by the charged dust cloud is shown in Figure 18. It was made of quarter-inch hardward screen. A potential of 20 kv was impressed on the shield during the desired test. After each test, the residual charge on the shield was discharged by connecting it to ground with a high-voltage probe.

The shield was placed parallel to and 3 1/4 inches away from the brass disc.

Operating Conditions

The following conditions were observed for all tests:

1. The relative humidity was held at sixty percent.

2. The air velocity was kept constant; with the blower speed set at 2500 revolutions per minute, the air velocity was 6000 feet per minute at the nozzle, and 800 feet per minute at the brass disc.

3. Ten grams of dust were evenly distributed by hand between two fixed marks, ten inches apart, lengthwise on the conveyor belt.

4. Four dusts were used: standard copper sulfate, micronized copper sulfate, standard Attaclay, and Attasorb. For a description and size analysis of these dusts the reader is referred to Appendix A.

5. The dust density was measured by drawing a known volume of the dust-laden air through a Millipore filter. The rate of flow through the filter was 20.4 liters per minute. Samples were taken for one minute during the uncharged test and during the 100-microampere test. The filters were weighed before and immediately after the sampling, to avoid possible errors due to moisture exchange with the surrounding atmosphere.

6. The brass disc was exposed to the dust stream 80 seconds during each test.

Experimental Design

The following current intensities were used:

0 (uncharged), 10, 20, 50, 75, 100, 150, 200, 300, 400, 500, and 600 microamperes. Two types of tests were run with these current intensities. In one type, the shield was not used; in the other the high potential of 20 kv was impressed on the shield.

A randomized block design with groups and sub-groups was used. The shielded and unshielded treatments were designated as groups to minimize the variations within one current intensity. Dusts were designated as sub-groups.

Each block was replicated four times. The order of blocks, groups, and sub-groups was determined randomly by drawing coded numbers from a box.

During the running of the tests, whenever a sign of dust contamination from one dust to another was noted, the tests were rerun after the experiment was completed. It turned out that this happened only during the early part of the experiment when the nozzle had not been cleaned often enough. If the rerun test included sampling with a Millipore filter, the weight of dust deposited on the filter was also recorded.

The dust deposit evaluation was made by direct weighing with an analytical balance.

Experimental Procedure

The experimental procedure was divided into two definite phases, the dusting and the evaluation of dust deposits on discs and on Millipore filters.

The evaluation phase consisted of weighing and recording weights of brass discs and of filters before and after dusting.

The dusting phase was composed of the following steps:

1. Starting the motor driving blower,
2. Installing the brass disc,
3. Checking the relative humidity and adjusting it if necessary,
4. Distributing the dust on the conveyor belt,
5. Installing a Millipore filter when needed,
6. Turning on charging circuit when necessary,
7. Starting cleaning brush at feed end of the conveyor belt,

8. Starting stop watch and conveyor belt simultaneously,
9. Exactly ten seconds later, starting vacuum pump to draw air through when Millipore filter was used,
10. Turning off pump exactly sixty seconds after it was started,
11. Ten seconds later, turning off charging circuit, stopping conveyor belt, cleaning brush, and blower,
12. Removing dusted disc and filter for evaluation,
13. Starting motor driving the blower, cleaning the nozzle,
14. Discharging the shield if it was used in the test,
15. Beginning again with step number 2.

Between steps 9 and 10, the appropriate dust was weighed for the next test.

Discussion of Results

Millipore Filter Deposits

The results of the Millipore filter deposits are tabulated in Appendix B, Table XI. Figure 22 shows the average filter deposits for the four dusts at three levels of treatment. Even though the same amount of dust was used, and the same volume of air was drawn through the Millipore filter each time, for each dust, the deposits during the uncharged tests are significantly larger than the deposits during both the charged tests and the charged and shielded tests. The filter deposits for the charged tests, and the charged and shielded tests, are approximately the same at

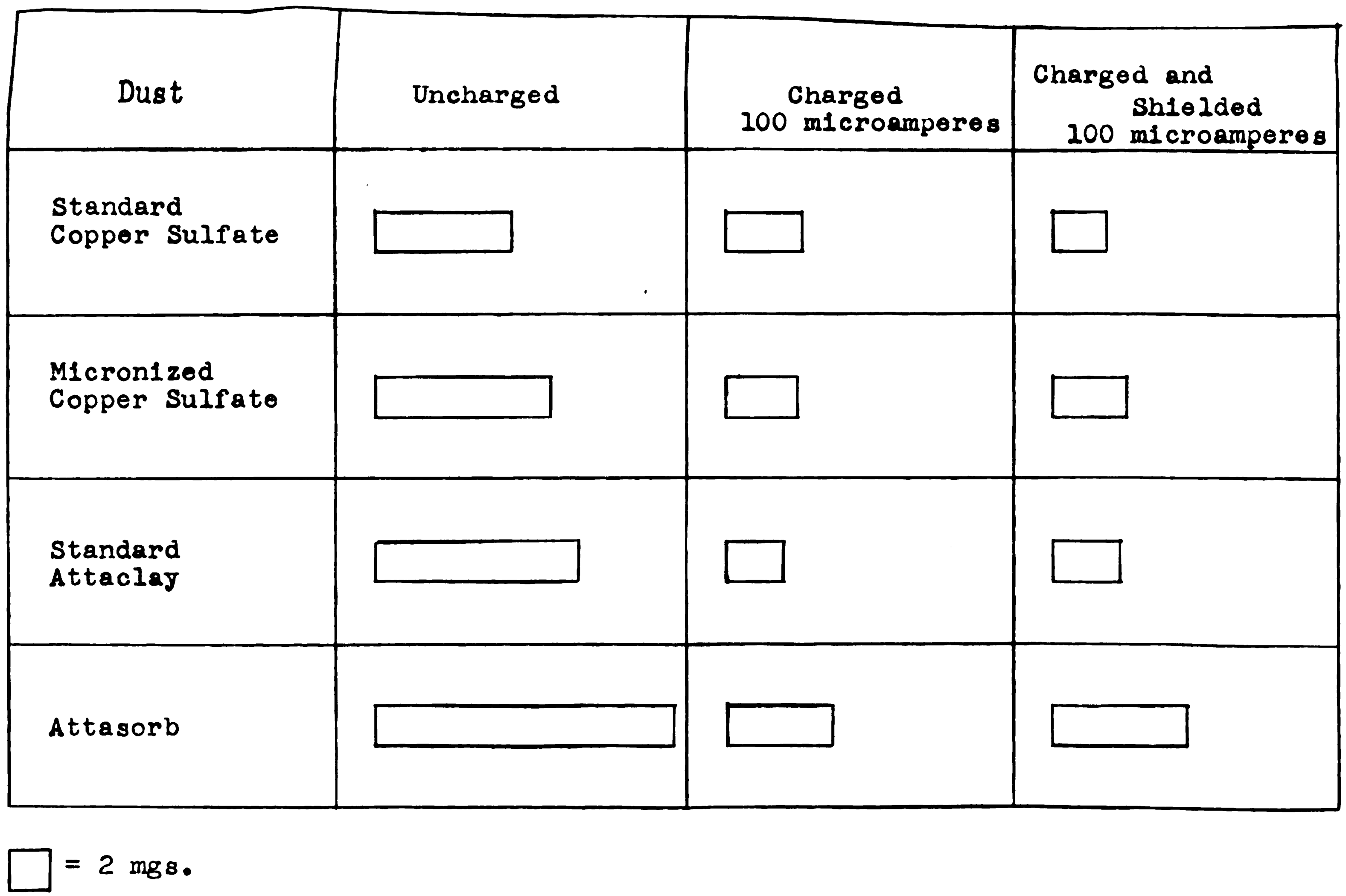

Fig. 22. Average Millipore filter deposits.
Weight in milligrams.

each level of treatment. It appears, then, that the charging of the dust may be responsible for the difference in filter deposits.

In order to account for the difference in filter deposits, the author suggests the following explanation. When the dust is uncharged, the dust cloud distributes itself evenly in the dusting chamber. When the dust is charged, or charged and shielded, the dust cloud has a positive sign. It tends to accumulate around the collector disc, at ground potential, and does not disperse itself toward the top of the dusting chamber where the Millipore filter holder is located (Fig. 17). Thus, the filter deposit becomes smaller, and, at the same time, the amount of dust precipitated on the collector disc becomes larger, because of the denser dust cloud surrounding it.

Effect of Current Intensities

Figure 23 shows the relationship between the charging currents and the applied voltages. According to the curve, ionization would occur around seven kilovolts.

The dusts deposited on collector discs are shown in Tables XIII and XIV, in Appendix B. Figures 24 and 25 show the average dust deposits at different levels of charging.

The charging of the four dusts used increased their depositions. For the same amount of dust used, the finely

ground dust -- micronized dust -- deposited more heavily than its coarser counterpart.

The standard Attaclay, the Attasorb, and the micronized copper sulfate showed a large increase in deposition when the current intensity was increased from zero to 150 microamperes. Beyond 150 microamperes, increased current intensities did not seem to increase dust depositions appreciably. The standard copper sulfate, however, showed a large increase in deposition around 500 microamperes, but its deposition reached a minimum at 600 microamperes. This sudden decrease in deposition was attributed to the breakdown of the charging nozzle, although the instruments did not register any breakdown during the tests.

The behavior of standard copper sulfate around the charging current intensity of 500 microamperes deserves some further study.

Effect of Shielding

For the two standard dusts -- Attaclay and copper sulfate -- shielding seemed to increase dust deposition at very low current intensities, 50 microamperes or less. Beyond these values, shielding did not seem to affect depositions of the standard dusts.

It is worthwhile to note that the "abnormal" behavior of the standard copper sulfate persisted with shielding.

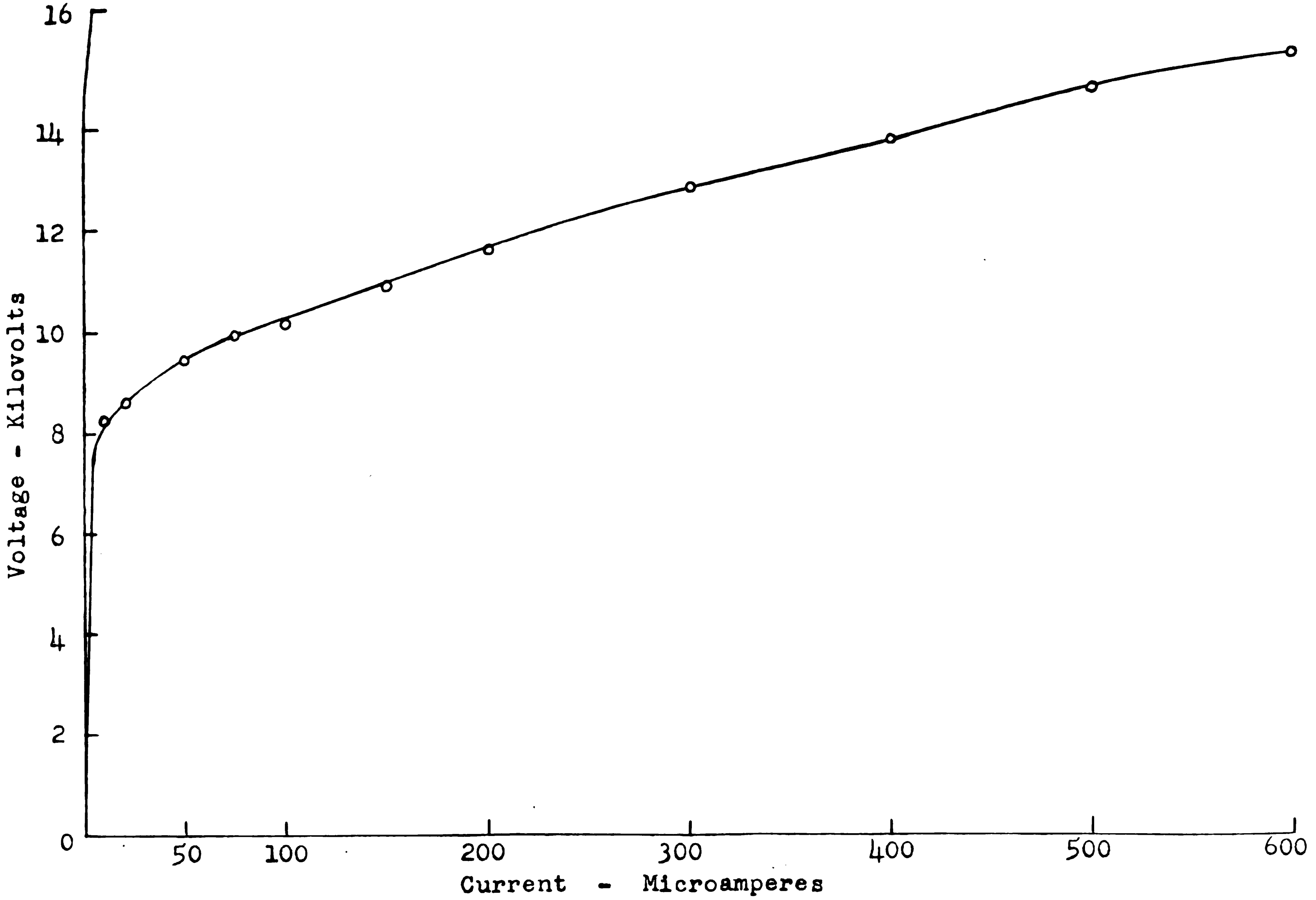

Fig. 23. Charging currents v/s applied voltages.

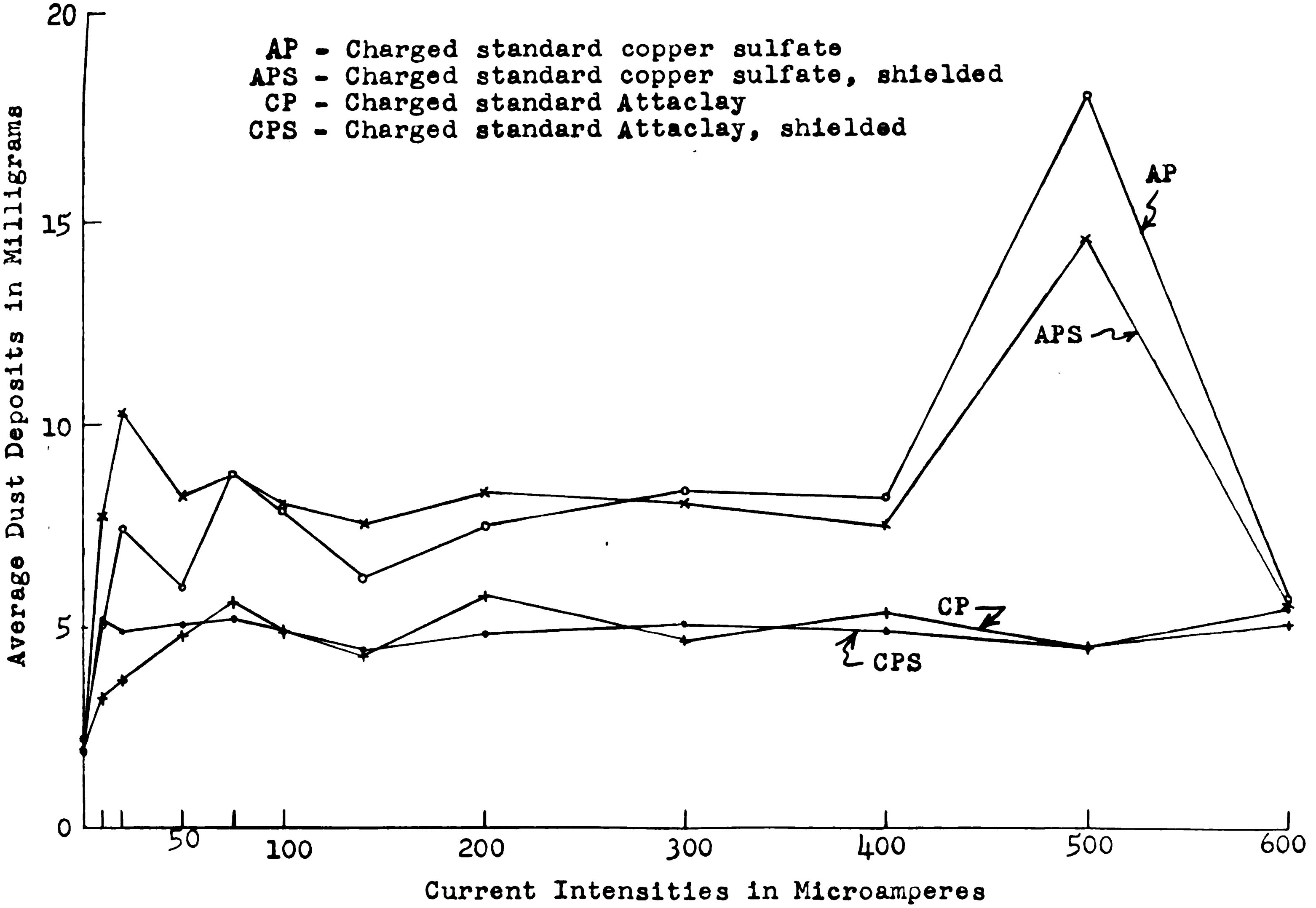

Fig. 24. Average dust deposits versus current intensities.

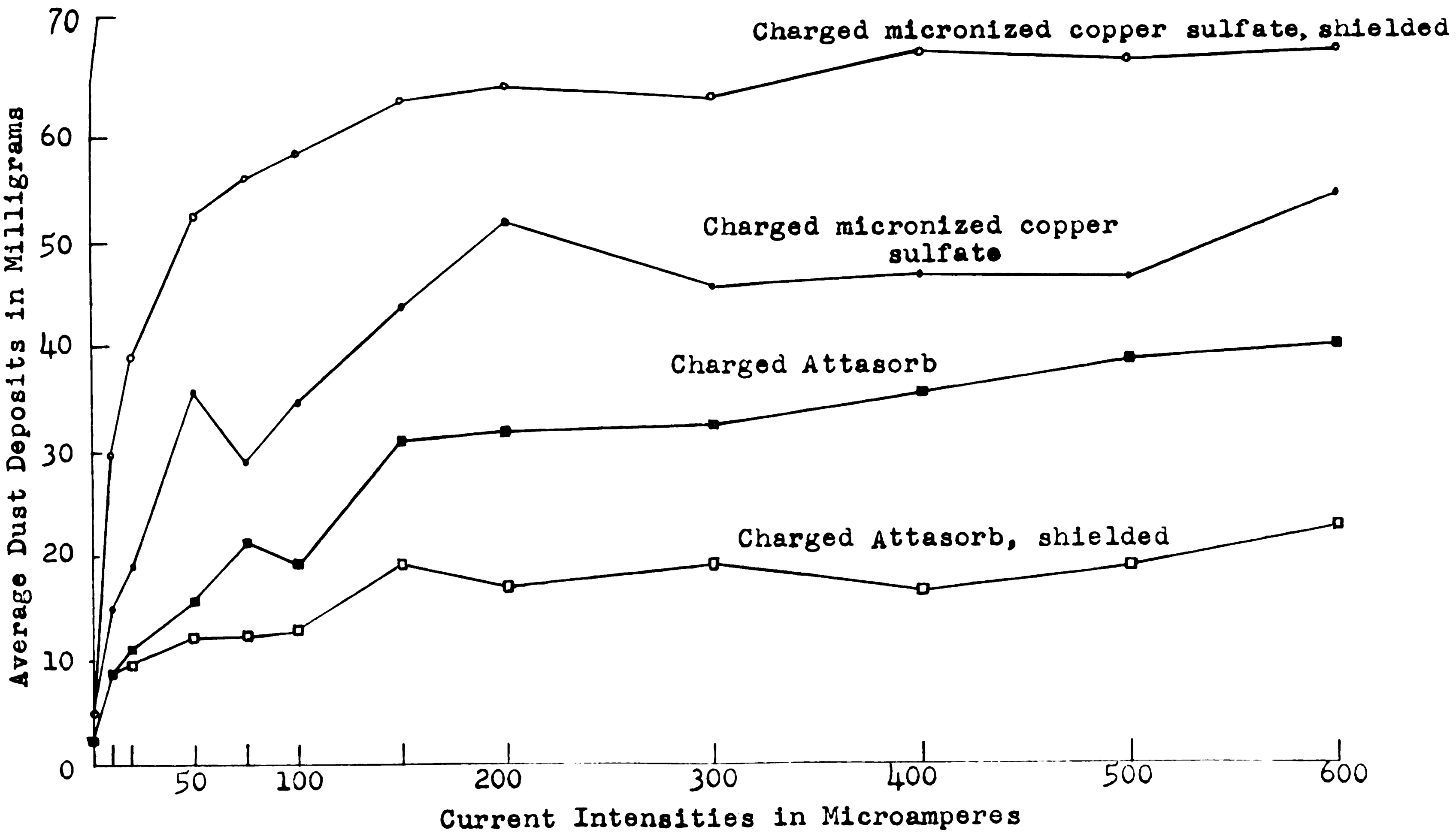

Fig. 25. Average dust deposits versus current intensities.

Shielding greatly increased the deposition of the micronized copper sulfate, but it substantially decreased the deposition of Attasorb. This decrease was totally unexpected. It was thought that the shield and the dust cloud produced by the charged Attasorb were of opposite signs. If it were true, then the dust, instead of depositing on the collector disc, would be precipitated onto the shield. Careful determination of the dust cloud sign, with an electroscope and a known source of positive charge, did not substantiate the hypothesis and it had to be discarded. The cause for the decrease in the deposition of Attasorb due to shielding remains, therefore, unknown.

Table VI shows quantitatively the effects on dust depositions due to charging or charging and shielding. The "charged" values and the "charged and shielded" values are the averages of deposits at the eleven levels of current intensities used. (See Table XIV, Appendix B.)

TABLE VI

AVERAGE VALUES OF DUST DEPOSITS DUE TO CHARGING OR CHARGING AND SHIELDING

(Weight in Milligrams)

	Standard Copper Sulfate	Micronized Copper Sulfate	Standard Attaclay	Attasorb
Uncharged	2.23	5.30	1.98	2.33
Charged[1]	8.14	38.42	4.79	25.81
Net Increase	5.91	33.12	2.81	23.48
Charged and Shielded[2]	8.66	57.39	4.94	15.36
Net Increase over "Uncharged"	6.43	52.09	2.96	13.03
Net Increase over "Charged"	+0.52	+18.97	+0.15	-10.45

[1] Average value of eleven levels of charging (see Table XIV).

[2] Average value of eleven levels of charging and shielding (see Table XIV).

SUMMARY AND CONCLUSIONS

The polarographic method of chemical analysis was applied to the evaluation of pesticidal dusts. Polarography was discussed briefly.

A Sargent Model III, manual type, polarograph was used to measure the concentration of copper in solutions containing hydrated copper sulfate. An electrolyte composed of 0.4 M potassium sulfate and 0.01 percent gelatin, was found suitable for the evaluation of copper sulfate dust.

Copper concentration as low as 1 ppm was readily measured in standard solutions prepared in the laboratory.

The polarographic method of evaluation was then used to measure deposits of copper sulfate dust on soybean leaves after field dusting. Five square inches of soybean leaves -- ten square inches of leaf area -- were punched into a wash solution containing potassium sulfate. The solutions were analyzed polarographically in the laboratory. This method was found to be satisfactory.

The field tests on soybean plants showed, in general, no difference in dust deposits between well-exposed and hidden leaves.

For the three rates of dust application used during the field experiment, the efficiency of the duster ranged between 13.3 percent and 22.7 percent for the conventional method of dusting, and between 14.5 percent and 27.1 percent for the electrostatic dusting.

The effect of current intensities on dust deposition was investigated in the laboratory under controlled conditions.

The laboratory tests indicated that for the micronized copper sulfate, Attaclay and Attasorb, the dust deposits increased greatly -- as many as ten times -- with increased current intensities up to 150 microamperes. With further increases in the current, the increase in dust deposit was negligible.

The standard copper sulfate showed a maximum deposition around 500 microamperes, and a sharp decrease at 600 microamperes.

Up to about 50 microamperes, shielding improved the deposition of coarse dusts -- standard copper sulfate and standard Attaclay -- at low current intensities. Above 50 microamperes, shielding did not seem to affect deposition.

Shielding greatly improved the deposition of the micronized copper sulfate, but it decreased the deposition of Attasorb.

APPENDIX A

PARTICLE SIZE DETERMINATION

Splinter (20), in his study on deposition of aerial suspensions of pesticides, and Brittain (7), in his study on the effect of plant surfaces on pesticidal dust deposition, both needed the distribution curves and the average size of the different dusts used during their respective investigations. The author did the following work to furnish them with the necessary information used in the quantification of their results.

Review of Literature

Particle size determination is of considerable importance in industry. It is also of great concern to chemists, to public health workers, and to many others. Methods have been devised by workers in their respective fields. A broad classification of these time-tested methods was given by Schweyer and Work (18) as follows:

I. Sieve analysis

II. Microscopic analysis
    A. Conventional microscopic methods
    B. Ultramicroscopic methods

- III. Sedimentation analysis
    - A. Increment methods
        - 1. Pipette method
        - 2. Hydrometer method
        - 3. Pressure method
        - 4. Photographic method
    - B. Cumulative methods
        - 1. Balance method
        - 2. Pressures methods
- IV. Centrifugal analysis
    - A. Ordinary centrifugal methods
    - B. Supercentrifuge methods
    - C. Ultracentrifuge methods
- V. Elutriation analysis
    - A. Air elutriators
    - B. Liquid elutriators
- VI. Turbidimetric analysis
    - A. Gross methods
    - B. Size distribution methods
- VII. Miscellaneous methods
    - A. Permeability methods
    - B. Adsorption methods

Crossmon (9) expressed satisfaction in the counting of dust particles by phase microscopy. Hillier (14) reported the use of the electron microscope in the determination of the size and shape of particles in the size range from 1μ to about $5 m\mu$. Jones (15) applied the microprojection technique to the determination of the size of fine abrasive powders, and found it satisfactory for symmetrically shaped abrasives.

The above-mentioned methods were included in this writing for future reference only. It is not the author's intention to discuss the merits and demerits of each method. The conventional microscopic method was chosen for the dete

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determination of dust sizes. This method was selected on the basis of reasonable accuracy, coupled with speed of operation. It also yields the size-distribution curve directly.

Equipment and Technique

A Bausch and Lomb laboratory microscope with a 10x eyepiece and a 43x objective, with numerical aperture 0.85 was used. A 100-watt spherical illuminator was the source of illumination.

Sampling

The dust contained in a bag was thoroughly mixed. A cotton-tipped applicator was then dipped, with a rotary motion, into the sample. A small portion of the dust adhered to the applicator. It was transferred to a clean microscopic glass slide by gently painting the glass surface with the applicator. A light blowing on the slide dispersed the dust clumps and a thin layer of dust was left on the glass slide ready for microscopic determination.

Counting

A magnification of 430x was used. Light-field illumination was selected because it was felt that submicroscopic particles ($<0.5\ \mu$) are relatively unimportant in dust deposition, and because the percentage by weight of these

submicroscopic particles would be negligible in the final analysis.

The linear measurement (Fig. 26) of the dust particles under the microscope was accomplished by a direct comparison with a scale incorporated in the ocular of the microscope. This scale was first calibrated against a stage micrometer.

Ten fields (Fig. 27) were picked on each slide, and four slides were prepared from each dust, totaling a count of forty fields for each dust studied.

The fields for counting were picked at random by moving the slides under the microscope. To count very small particles ($\leqslant 1\mu$), the slide was moved slightly sideways; the particles were then seen moving and more easily detected. They showed up as gray specks and were not as well defined as particles above 1μ.

Results

Particle size determinations were made for the following dusts[1]:

1. Micronized talc (sack 1)

---

[1] Because of an error in labeling the various sacks of dust when Splinter and the author were working together, some of the dusts coming from different bags were analyzed twice. The author then went ahead and presented the data as if all the dusts were different from one another. He left to the discretion of Splinter the decision to lump the data from the same dusts together for final analysis.

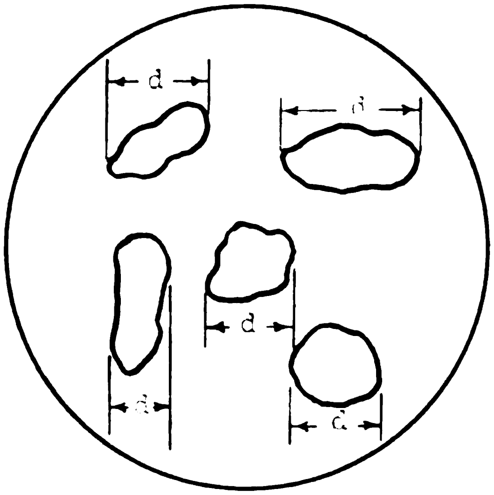

Fig. 26. Linear measurement of dust particle.

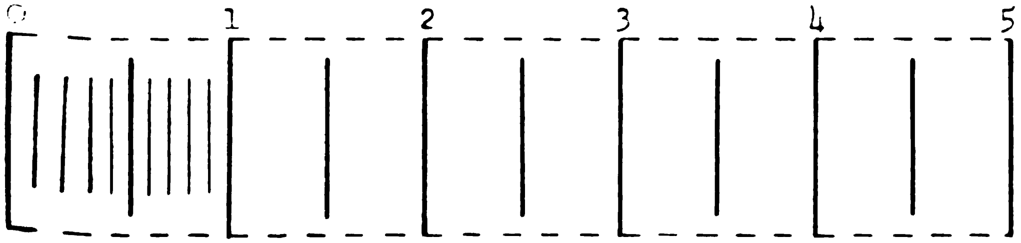

Fig. 27. Shows the objective scale, the area enclosed by the dotted line constitutes one counting field.

2. Micronized Attaclay (sack 1)
3. Red-dyed talc
4. Standard Attaclay
5. Micronized clay (Attasorb)
6. Standard talc
7. Micronized talc (sack 2)
8. Micronized Attaclay (sack 2)
9. Micronized copper sulfate (Cu SO_4 , $5H_2O$)
10. Standard copper sulfate (Cu SO_4, $5H_2O$)

The results were tabulated in Table VIII and the size-frequency curves plotted from Table VI are shown in Figures 28, 29, and 30.

The standard talc and Attaclay (Fuller's earth) dusts were 25-mesh dusts used as commercial fillers. The standard copper sulfate was a commercially available dust under the name "powdered bluestone." The micronized talc, Attaclay, and copper sulfate were obtained by running the regular dusts through a micronizer. This operation was described by Brittain (7, page 32). The red talc was micronized talc which had been mixed with a water-soluble red organic dye, Luxol Scarlet (6), and then reground. The Attasorb was a commercially available finely ground clay.

Average Diameters

The median diameter of each dust was determined from the size-frequency curves. According to Green's definition (11), an average diameter is the diameter of a hypothetical particle which in some ways represents the total number of particles in a sample. A full description of the size of a non-uniform particulate substance requires the determination of several average diameters (10). Drinker and Hatch (10, page 147) listed the mathematical definitions of the several average diameters necessary for a complete definition of size. Only the average diameter from the arithmetic mean was presented in this result, because it was felt that this value was adequate (Table VII).

SIZE - FREQUENCY CURVE

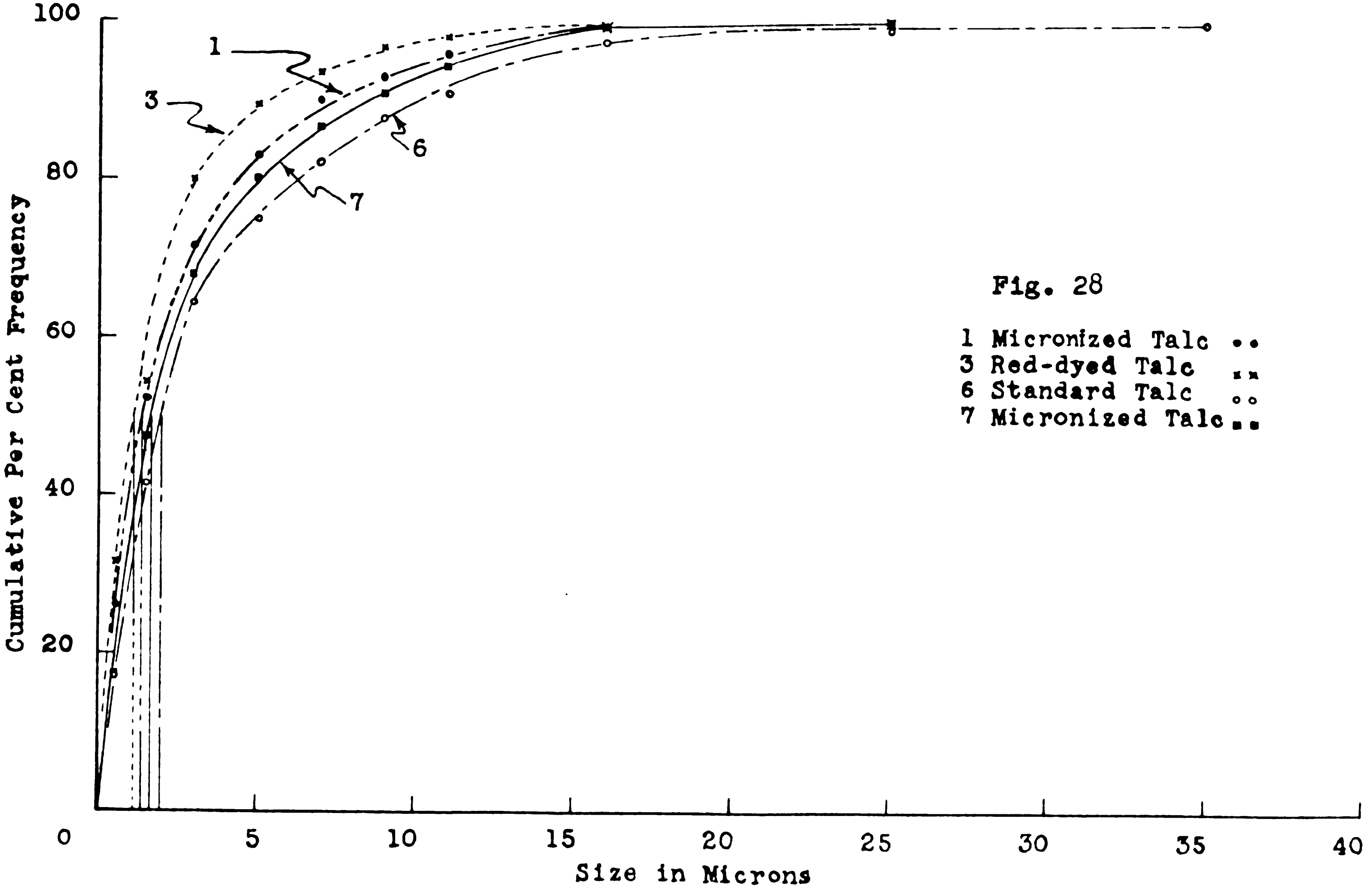

Fig. 28

SIZE - FREQUENCY CURVE

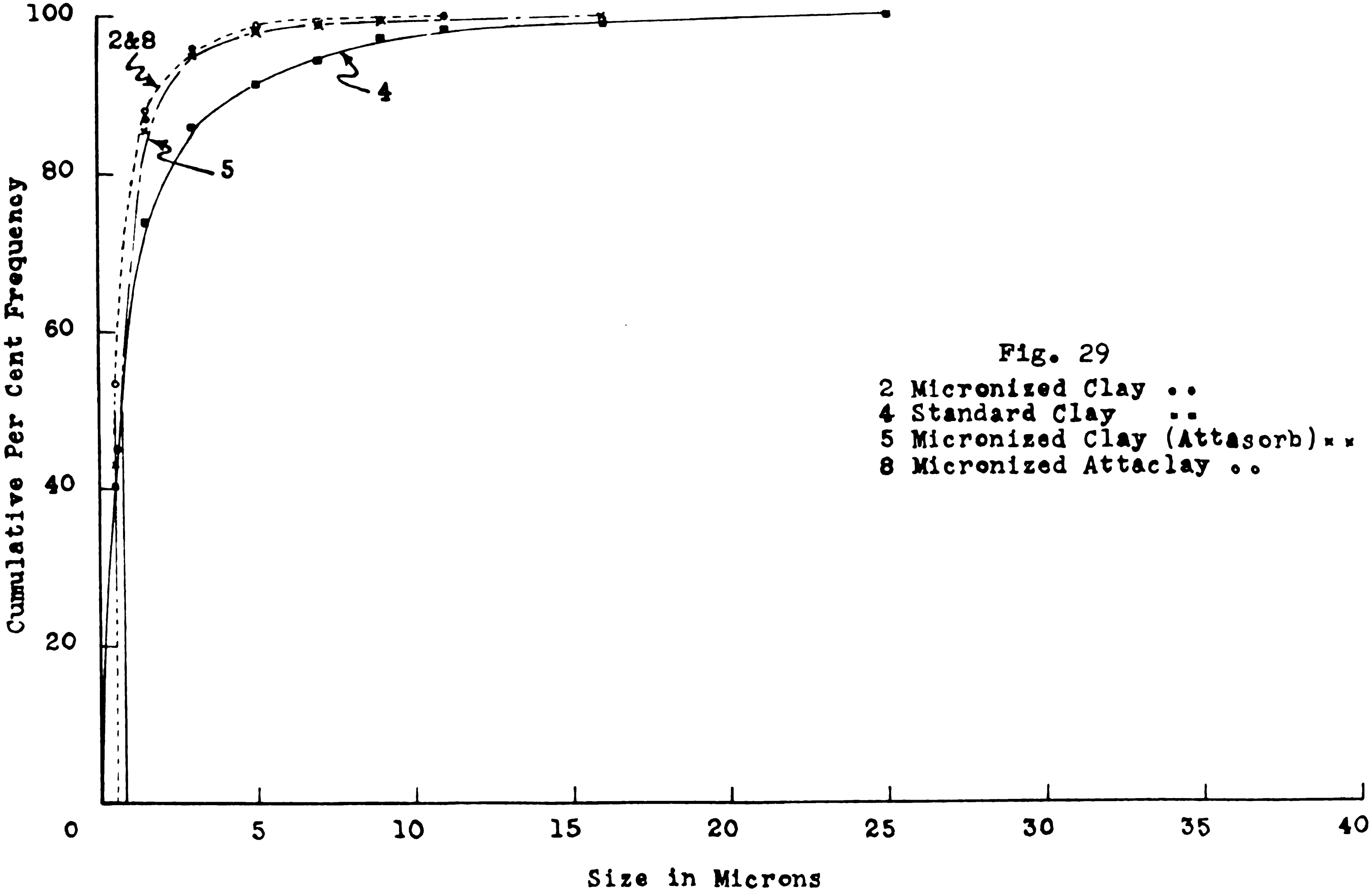

Fig. 29

2 Micronized Clay • •
4 Standard Clay ▪ ▪
5 Micronized Clay (Attasorb) × ×
8 Micronized Attaclay ○ ○

SIZE - FREQUENCY CURVE

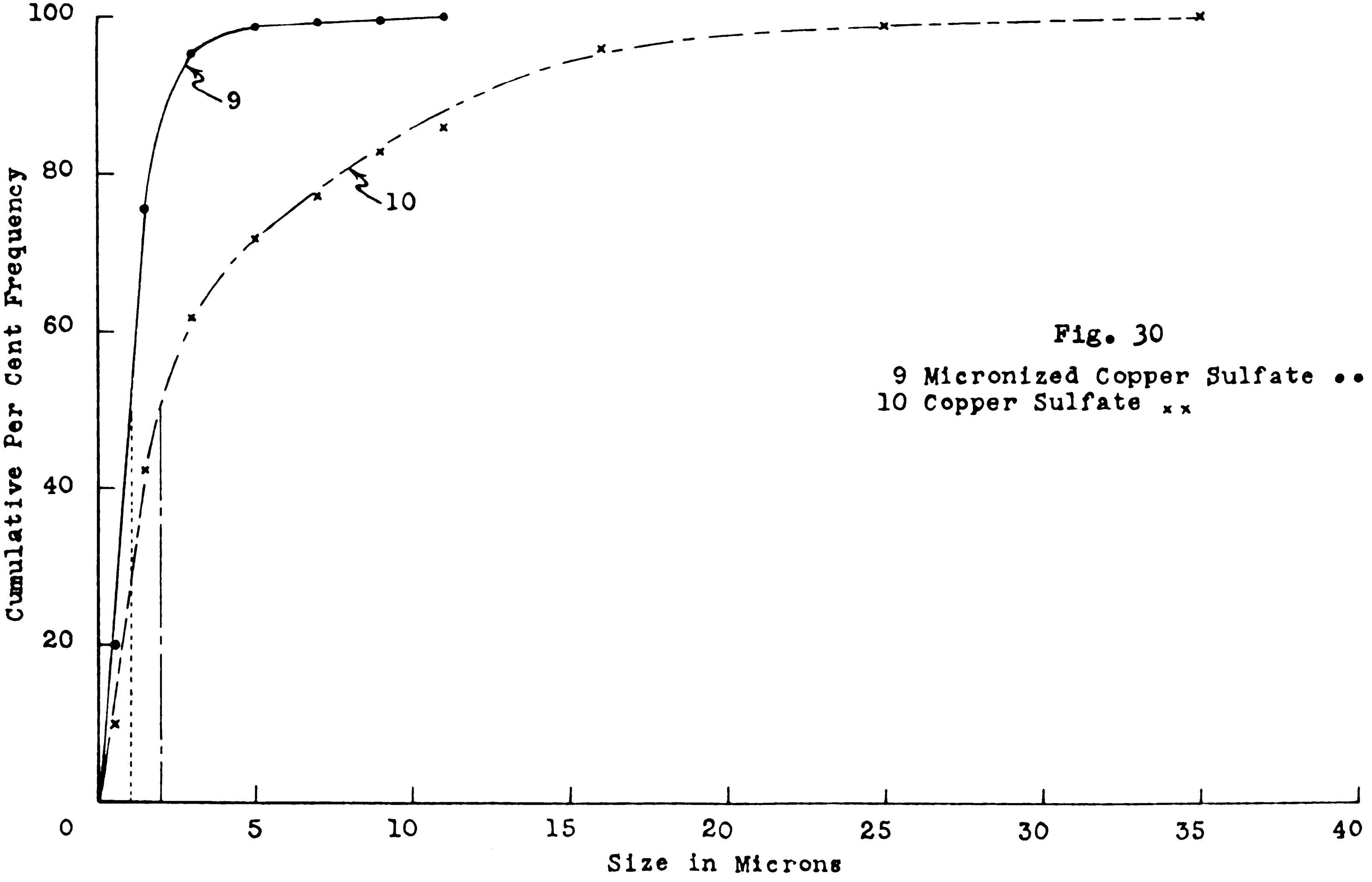

Fig. 30

9 Micronized Copper Sulfate ●●
10 Copper Sulfate ××

TABLE VII

CUMULATIVE SIZE-FREQUENCY DISTRIBUTION

Dust	Diameter in microns									
	0.5	1.5	3.0	5.0	7.0	9.0	11.0	16.0	25.0	35.0
Micronized talc (sack 1)	26.0	52.3	71.5	82.9	89.8	93.1	95.8	99.6	100.0	
Micronized Attaclay (sack 1)	45.4	87.2	95.9	98.4	99.1	99.7	100.0			
Red-dyed talc	31.4	64.4	79.7	89.3	93.7	96.6	98.1	99.8	100.0	
Standard Attaclay	40.1	73.9	85.8	91.6	94.4	96.8	98.3	99.9	100.0	
Micronized clay (Attasorb)	43.3	85.8	95.6	98.3	99.3	99.8	99.9	100.0		
Standard talc	17.3	41.4	64.3	74.9	82.1	87.8	91.3	97.6	99.1	100.0
Micronized talc (sack 2)	17.8	47.5	68.0	79.8	86.6	91.2	94.5	99.5	100.0	
Micronized Attaclay (sack 2)	53.5	87.9	96.2	98.6	99.2	99.6	99.9	100.0		
Micronized copper-sulfate	20.0	75.7	95.4	98.7	99.6	99.9	100.0			
Standard copper-sulfate	10.0	42.3	61.8	72.0	77.4	82.8	86.1	96.3	99.1	100.0

TABLE VIII

AVERAGE DIAMETERS AND DENSITIES OF DUSTS

Dust	Average Diameter		Particle Density	Reference
	Arithmetic Mean (microns)	Median[1] (microns)	(gm/cm^3)	
Micronized talc (sack 1)	3.44	1.40	2.8	(22)
Micronized Attaclay (sack 1)	1.37	0.50	2.45	(1)
Red-dyed talc	2.63	1.10	--	
Standard Attaclay	2.21	0.80	2.45	(1)
Micronized clay (Attasorb)	1.41	0.80	2.45	(1)
Standard talc	4.74	2.00	2.8	(22)
Micronized talc (sack 2)	3.93	1.70	2.8	(22)
Micronized Attaclay (sack 2)	1.28	0.50	2.45	(1)
Micronized copper-sulfate	1.79	1.00	--	
Standard copper-sulfate	5.50	2.00	--	

[1] From size-frequency curves, Fig. 28, 29, and 30.

TABLE IX

PARTICLE SIZE DATA

Dust	Rep.	Diameter in Microns									
		≤1	1-2	2-4	4-6	6-8	8-10	10-12	12-20	20-30	≥30
Micronized talc (sack 1)	1	75	83	77	36	22	6	7	12	1	
	2	68	80	61	37	14	9	7	4	1	
	3	57	51	29	28	19	14	9	7		
	4	70	58	33	17	16	5	5	16	2	
Micronized Attaclay (sack 1)	1	146	144	41	13	6	3				
	2	266	223	41	15	1	2				
	3	172	140	28	8	2	3	3			
	4	209	223	42	7	4	1	2			
Red-dyed talc	1	132	96	49	37	18	18	6	13	2	
	2	40	69	44	21	8	9	5	6		
	3	88	145	76	46	17	10	4	1		
	4	148	117	29	20	14	1	4	2		
Standard Attaclay	1	116	73	34	21	8	8	3	4	1	
	2	75	78	16	10	8	6	6	3		
	3	92	88	37	9	5	4	2	6		
	4	92	77	24	15	5	4	3	2		
Micronized clay (Attasorb)	1	139	143	30	12	4	1				
	2	129	146	32	7	5	1		1		
	3	179	171	39	9	2	3				
	4	180	156	40	11	3	2	1			
Standard talc	1	21	59	53	26	18	15	6	14	2	1
	2	36	57	55	19	14	9	9	9	1	1
	3	38	30	27	22	10	11	8	14	5	3
	4	43	46	47	18	15	10	5	13	4	2
Micronized talc (sack 2)	1	35	64	46	29	17	11	8	11	1	
	2	44	72	36	17	16	10	6	14	1	
	3	43	67	59	33	12	10	5	6	1	
	4	41	70	47	29	18	11	11	15	2	
Micronized Attaclay (sack 2)	1	182	137	38	6	4	1	1			
	2	192	132	33	8	4	1				
	3	215	145	35	13	1	4	2	1		
	4	209	97	17	9			1	1		
Micronized copper sulfate	1	42	126	51	9	2					
	2	44	90	18	5	1					
	3	42	112	29	7	2					
	4	31	115	39	5	2	2	1			
Standard copper sulfate	1	9	42	24	11	7	5	6	11	2	
	2	5	42	20	12	4	6	4	13	3	1
	3	14	30	20	14	7	9	3	11	2	1
	4	18	35	26	10	7	5	2	12	6	2

APPENDIX B

EXPERIMENTAL RESULTS

TABLE X

DATA OF FIELD TESTS OF SOYBEANS DUSTED WITH STANDARD COPPER SULFATE

(Weight in milligrams)

Rate	Top Leaves		Hidden Leaves	
	Uncharged	Charged	Uncharged	Charged
Low	0.10	0.69	0.10	0.90
	0.20	1.19	0.42	0.48
27.2 lbs.	0.59	0.41	0.96	0.36
per acre	0.12	0.43	0.59	0.59
	0.69	0.24	0.68	0.43
	0.36	0.26	0.56	0.23
	0.27	0.32	0.60	0.32
	0.36	0.21	0.37	0.56
Medium	0.39	1.08	1.44	0.94
	0.42	2.27	1.87	1.11
42.3 lbs.	0.39	2.01	0.85	1.69
per acre	1.45	1.69	0.90	1.92
	0.43	0.20	0	0.72
	0.41	1.66	0	2.70
	0	0.20	0	0.71
	0	0.90	0	0.72
High	0.78	4.31	2.16	3.99
	1.64	1.30	1.73	1.56
68.2 lbs.	0.59	2.38	1.89	1.65
per acre	0.86	2.77	1.93	2.23
	2.16	1.60	5.00	2.65
	3.20	1.80	3.80	0.81
	0.63	2.58	0.65	1.26
	0.52	3.00	2.36	1.71

TABLE XI

MILLIPORE FILTER DEPOSITS

(Weight in milligrams)

Dust	Standard Copper Sulfate		Micronized Copper Sulfate		Standard Attaclay		Attasorb	
Uncharged	4.6	7.0	8.5	7.6	7.3	11.5	13.0	18.9
	6.5	8.0	9.2	8.3	13.4	8.7	11.9	13.4
					7.7			
Average deposit	6.53		8.40		9.72		14.30	
Charged (100 microamperes)	3.8	5.7	5.0	3.3	4.0	2.8	6.6	5.1
	2.9	2.6	3.2	2.9	3.4	2.5	5.7	3.6
					3.1	2.0		
Average deposit	3.75		3.60		2.97		5.25	
Charged and Shielded (100 microamperes)	2.4	2.9	4.2	3.6	4.1	2.7	6.2	6.7
	3.3	2.0	3.5	2.9	4.8	2.8	7.4	5.8
					2.6	2.0		
Average deposit	2.65		3.55		3.17		6.53	

TABLE XII

DATA SHOWING THE CURRENT-VOLTAGE RELATIONSHIP DURING IONIZATION

Current Intensities Microamperes	Voltage - Kilovolts												Total	Average Kilovolts
10	8.3	8.3	8.2	8.3	8.3	8.2	8.2	8.2	8.2	8.2	8.2	8.2		
	8.2	8.2	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.3	8.1	8.4	231.2	8.26
	8.3	8.2	8.7	8.7										
20	8.6	8.6	8.5	8.5	8.5	8.6	8.8	8.6	8.6	8.9	8.6	8.6		
	8.7	8.6	8.4	8.6	8.5	8.6	8.5	8.5	8.7	8.4	8.5	8.4	222.8	8.57
	8.5	8.5												
50	9.3	9.8	9.7	9.5	9.8	9.4	9.5	9.3	9.4	9.4	9.4	9.8		
	9.4	9.4	9.4	9.4	9.3	9.3	9.5	9.4	9.4	9.4	9.5	9.8	340.5	9.46
	9.6	9.4	9.4	9.4	9.4	9.3	9.8	9.4	9.4	9.3	9.3	9.3		
75	9.8	9.9	9.9	9.8	9.9	9.9	9.9	9.9	9.9	9.9	9.7	9.8		
	9.9	9.8	9.8	9.8	9.6	9.8	10.3	10.5	9.8	9.9	9.9	10.3	266.4	9.87
	9.9	9.9	9.9											
100	10.1	10.2	10.1	10.2	10.2	10.0	10.3	10.2	10.1	10.4	9.9	10.0		
	9.8	10.4	10.4	9.9	10.0	10.4	10.5	10.0	10.3	10.2			223.6	10.17

TABLE XII (Cont.)

Current Intensities Microamperes	Voltage - Kilovolts												Total	Average Kilovolts
150	10.9	10.8	11.0	10.9	10.9	11.0	10.8	11.0	10.9	10.9	10.9	10.9		
	10.9	10.8	11.4	11.2	10.9	10.9	10.8	11.0	11.0	10.8	10.6	10.9	327.3	10.91
	11.0	10.9	10.8	10.9	10.7	10.9								
200	11.5	11.6	11.4	11.4	11.9	11.6	11.8	11.6	11.6	11.6	11.6	11.5		
	11.5	11.4	11.5	11.6	11.4	11.8	11.8	11.8	11.6	11.5	11.5	11.5	347.9	11.60
	12.4	11.5	11.3	11.4	11.5	11.8								
300	13.4	12.9	12.7	12.9	12.9	12.8	12.8	12.7	12.9	12.6	12.7	13.0		
	13.3	12.6	12.9	12.9	12.7	12.8	13.0	13.5	12.8	12.5	12.6	12.9	462.1	12.83
	12.5	12.8	12.6	12.5	12.7	12.6	12.5	12.7	13.2	13.0	12.9	13.3		
400	13.9	13.7	14.4	13.9	14.0	13.9	13.8	13.8	13.9	13.8	13.7	13.7		
	14.7	13.6	13.7	13.5	14.2	13.7	12.4	13.6	13.7	13.6	13.7	13.7	399.6	13.77
	13.8	13.9	13.9	13.7	13.7									
500	14.6	14.6	14.5	14.8	14.6	14.6	14.9	14.9	15.2	15.4	14.5	14.5		
	14.6	14.6	15.5	14.8	15.6	15.0	14.6	15.1	14.6	14.4	14.6	15.0	444.8	14.82
	15.6	15.0	14.6	14.5	14.8	14.8								
600	15.6	15.4	15.6	15.5	16.6	15.7	15.5	15.6	15.4	15.5	15.4	16.7		
	16.5	15.4	15.8	15.4	16.3	15.5	15.5	15.8	15.6	15.6	15.3	16.5	542.0	15.50
	17.0	15.4	15.6	15.8	15.9	15.6	15.6	15.4	16.5	15.9	15.6			

TABLE XIII

RESULTS OF TESTS ON THE EFFECT OF CURRENT INTENSITIES
AND SHIELDING ON DUST DEPOSITS
(Weight in milligrams)

Current in Microamperes	Standard Copper Sulfate				Micronized Copper Sulfate				Standard Attaclay				Attasorb			
	Charged		Charged and Shielded		Charged		Charged and Shielded		Charged		Charged and Shielded		Charged		Charged and Shielded	
0 or Uncharged	1.5	2.2	3.4	1.8	4.0	3.6	5.7	7.9	2.2	1.7	2.5	1.5	2.3	3.0	2.0	2.0
10	5.1	4.7	8.5	7.5	9.2	19.7	25.1	32.4	3.4	4.0	5.4	5.6	8.3	9.6	8.6	9.8
	3.4	6.9	7.3	8.2	14.7	16.1	30.1	30.8	3.1	2.8	5.0	4.6	9.8	6.5	9.1	6.8
20	5.2	9.9	8.4	12.4	14.0	15.3	31.6	37.3	4.1	3.0	5.8	4.7	10.0	11.0	8.8	10.1
	7.1	7.7	11.9	8.7	24.0	23.2	43.0	44.0	4.0	3.6	5.1	4.3	10.9	10.4	9.6	9.5
50	6.9	4.7	8.2	7.5	43.3	37.6	50.5	46.8	3.6	4.3	4.1	6.2	15.0	19.2	12.9	11.3
	6.1	6.3	8.6	8.7	24.0	38.3	51.9	60.5	3.9	7.6	4.9	5.0	13.6	15.4	12.7	11.4
75	6.1	7.1	7.4	7.0	26.9	35.6	52.2	56.2	6.5	8.2	6.5	5.7	17.4	21.1	11.8	11.4
	9.4	13.8	8.9	12.9	30.4	23.0	65.5	50.5	3.1	4.7	4.1	4.5	23.1	22.8	13.0	12.4
100	10.5	6.5	8.6	7.9	44.3	33.3	58.4	55.2	2.8	4.1	3.8	4.9	14.0	25.5	11.9	16.4
	6.8	7.8	7.9	7.8	26.6	33.5	62.1	58.0	3.9	8.9	4.9	6.1	15.7	20.0	10.9	12.2
150	6.0	5.0	7.1	7.6	53.9	42.3	50.9	72.1	4.5	6.7	4.2	6.7	33.9	33.8	27.6	19.5
	6.2	7.7	7.1	8.5	37.6	41.2	68.1	63.0	2.7	3.6	3.4	3.6	28.2	29.0	16.5	13.3
200	6.4	9.9	7.3	11.8	57.2	38.3	57.5	69.4	8.8	5.3	5.3	5.2	35.1	32.5	16.5	17.0
	5.1	8.6	7.7	6.7	61.4	50.8	65.7	67.8	5.5	3.6	5.2	3.8	25.0	34.4	18.4	16.4

TABLE XIII (Cont.)

Current in Microamperes	Standard Copper Sulfate				Micronized Copper Sulfate				Standard Attaclay				Attasorb			
	Charged		Charged and Shielded		Charged		Charged and Shielded		Charged		Charged and Shielded		Charged		Charged and Shielded	
300	7.4	9.0	7.2	7.5	34.4	63.4	60.4	46.4	3.3	8.1	3.3	7.9	27.8	33.2	18.8	23.4
	9.5	7.7	9.3	8.4	44.0	41.0	76.8	71.0	3.2	4.0	4.3	4.8	27.5	40.0	15.6	18.9
400	6.8	7.1	7.4	8.0	42.5	50.9	55.7	74.6	7.8	4.0	5.2	3.7	34.4	34.7	16.5	18.2
	11.3	7.8	8.2	6.6	42.6	51.0	72.3	69.3	3.8	6.0	3.9	5.0	34.7	37.5	15.9	15.4
500	11.0	21.0	10.8	17.7	44.2	39.9	53.6	78.7	6.7	4.2	6.9	4.0	33.7	37.7	22.1	19.8
	13.6	27.0	12.5	16.9	42.3	59.9	69.0	68.1	4.4	2.7	4.3	3.0	38.3	44.8	16.0	18.6
600	5.6	5.4	5.4	5.5	54.2	43.6	72.0	58.4	5.6	4.7	5.0	4.9	42.8	36.2	20.9	20.9
	6.2	5.8	6.1	5.6	69.9	51.0	66.0	76.6	5.8	6.0	5.7	4.6	40.0	41.1	21.9	27.0

TABLE XIV

ARITHMETIC MEAN OF DUST DEPOSITS ON DUST COLLECTOR DISCS

(Weight in milligrams)

	Current in	Standard Copper Sulfate		Micronized Copper Sulfate		Standard Attaclay		Attasorb	
	Microamperes	Charged	Charged and Shielded	Charged	Charged and Shielded	Charged	Charged and Shielded	Charged	Charged and Shielded
Total Mean	0 or Uncharged	8.9 2.23		21.2 5.30		7.9 1.98		9.3 2.33	
Total Mean	10	20.1 5.02	31.5 7.87	59.7 14.92	118.4 29.60	13.3 3.32	20.6 5.15	34.2 8.55	34.3 8.57
Total Mean	20	29.9 7.48	41.4 10.35	76.5 19.12	155.9 38.95	14.7 3.68	19.9 4.98	42.3 10.58	38.0 9.50
Total Mean	50	24.0 6.00	33.0 8.25	143.2 35.80	209.7 52.42	19.4 4.85	20.2 5.05	63.2 15.80	48.3 12.08
Total Mean	75	36.4 8.85	36.2 8.80	115.9 28.97	224.4 56.10	22.5 5.62	20.8 5.20	84.4 21.10	48.6 12.15
Total Mean	100	31.6 7.90	32.2 8.05	137.7 34.45	233.7 58.42	19.7 4.92	19.7 4.92	75.2 18.80	51.4 12.85
Total Mean	150	24.9 6.22	30.3 7.58	175.0 43.75	254.1 63.52	17.5 4.38	17.9 4.48	124.9 31.22	76.9 19.22
Total Mean	200	30.0 7.50	33.5 8.38	207.7 51.92	260.4 65.10	23.2 5.80	19.5 4.88	127.0 31.75	68.3 17.08

TABLE XIV (Cont.)

	Current in Microamperes	Standard Copper Sulfate		Micronized Copper Sulfate		Standard Attaclay		Attasorb	
		Charged	Charged and Shielded	Charged	Charged and Shielded	Charged	Charged and Shielded	Charged	Charged and Shielded
Total	300	33.6	32.4	182.8	254.6	18.6	20.3	128.5	76.7
Mean		8.40	8.10	45.70	63.65	4.65	5.08	32.12	19.18
Total	400	33.0	30.2	187.0	271.9	21.6	17.8	141.3	66.0
Mean		8.25	7.55	46.75	67.98	5.40	4.95	35.32	16.50
Total	500	72.6	57.9	186.3	269.4	18.0	18.2	154.5	76.5
Mean		18.15	14.62	46.58	67.37	4.50	4.55	38.62	19.12
Total	600	23.0	22.6	218.7	273.0	22.1	20.2	160.1	90.7
Mean		5.75	5.65	54.68	68.25	5.52	5.05	40.02	22.68

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