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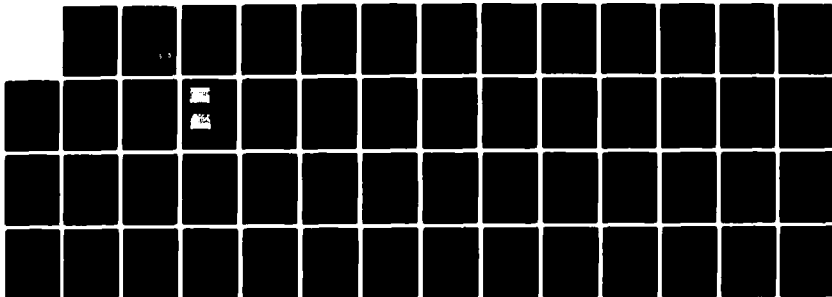
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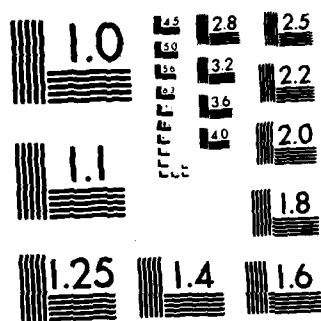
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MEASUREMENT OF DROPLET SIZE DISTRIBUTION  
IN INSECTICIDE AND HERBICIDE SPRAYS

Phase I Final Report

by

David S. Mahler

April 1983

(For 1 December, 1981 - 14 April, 1983)

Supported by

US Army Medical Research and Development Command  
Fort Detrick, Frederick, Maryland 21701

Contract No. DAMD17-82-C-2042

KLD Associates, Inc.  
300 Broadway  
Huntington Station, New York 11746

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The results of this research are very encouraging and a Phase II research plan is recommended to study actual insecticides of interest to the U.S. Army.

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### ABSTRACT

The work presented in this report investigates the applicability of using hot-wire instrumentation for the measurement of the droplet size distributions of insecticide and herbicide sprays. Under Phase I, mineral oil was used as a model liquid. Tests were performed to determine the effects of eccentric collisions, longitudinal variations along the wire, probe contamination, and temperature stability. A calibration curve was obtained for mineral oil which is different than that of water. This calibration curve shows that the hot-wire approach is accurate for a size range of 1 to 240  $\mu\text{m}$ . This range is more than adequate for existing insecticide spray apparatus. Tests using actual insecticides have shown that the calibration curve obtained for mineral oil may also be used for at least the two insecticides investigated.

The results of this research are very encouraging and a Phase II research plan is recommended to study actual insecticides of interest to the U.S. Army.

## 1. INTRODUCTION

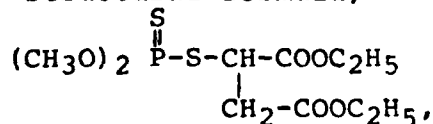
The purpose of the present research program is to investigate and to evaluate the applicability of a field portable device (DC-2A) for the measurement of droplet size distributions of insecticide and herbicide sprays. The instrument cited uses a heated platinum wire as a sensing element and was initially developed (1,2) to study sprays of water and aqueous solutions contained in the gas streams of scrubbers and mist eliminators. To date, it has been used for a wide range of investigations (3,4) to characterize spray nozzles, demister efficiencies, and to measure volume flow of water in droplet form, within the size range of the instrument. Three generations of this device have been commercially available with the second generation (DC-2) previously used by Army personnel for preliminary investigations (5).

### 1.1 Project Objectives

To demonstrate the applicability of the DC-2A for the measurement of insecticide and herbicide sprays a research project was defined with the following tasks:

- 1) Investigate effects of eccentric collisions and wire mounting terminals
- 2) Develop apparatus for size calibration
- 3) Investigate contamination of sensor
- 4) Investigate temperature stability of wire sensor
- 5) Calibrate device for water and mineral oil
- 6) Assess accuracy of device.

For this experimental study, a DC-2A (third generation of the instrument) was modified and used to study mineral oil. Although mineral oil is not necessarily an ideal model for insecticides, it is a petroleum oil, with typically 10 to 12 carbon atom groupings, and it is a better model of such materials as malathion (0,0 - dimethyl phosphorodithioate of diethyl mercaptosuccinate) represented by the structural formula,



than water or aqueous solutions. Some of the important physical parameters are summarized in Table 1 for water, mineral oil and malathion. It can be seen that mineral oil has more properties similar to malathion than to water. For large-scale aerial spraying, materials such as malathion are used in concentrated form as opposed to being diluted by water. For reasonably dilute solutions, there is no reason to question the calibration of the DC-2A, depending on the solute. However, for materials such as mineral oil which has a significantly different surface tension than water, it is expected that measurable differences in the calibration curve will exist. The calibration curve is discussed in more detail in Section 2.5 of this report.

## 1.2 Principles of Operation of the DC-2A

The principle of operation of the hot-wire droplet sensor is based on the cooling caused by a droplet attaching to the hot-wire. The concept is schematically shown in Figure 1, where the hot-wire sensor and its idealized uniform longitudinal temperature distribution are shown before (a) and after (b) a water droplet (shaded circle) attaches. The electrical resistance of the wire is a function of the wire temperature which in (a) is high and idealized to be constant along the length of the wire. In situation (b), the portion of the wire covered by the droplet is cooled to approximately the droplet temperature. A constant electrical current, which flows along the wire to heat it, shows a measurable voltage drop across the wire supports when a droplet is attached to the wire. The voltage encountered before droplet attachment (a) is reduced for condition (b) in direct proportion to the cooled length of wire; i.e., the droplet diameter. The electrical energy delivered to the wire evaporates the water, leaving the sensor dry and ready for further interaction.

The above description of the principle of operation of the instrument is an idealization, and in actual practice, the electrical signal obtained during a droplet/hot-wire interaction is shown in Figure 2. Reduction of the voltage implies cooling of the wire. An initial fast decay of the signal is observed; it corresponds to the initial lateral contact of the droplet and wire with a basically radial cooling of the wire. The duration of this portion of the signal is on the order of a few microseconds. The less steep signal following the initial contact is caused by the droplet centering around the wire due to surface tension and by the longitudinal cooling of the wire beyond the area covered by the droplet. During this time, a warming of the droplet-wire takes place, raising the signal until the boiling temperature is reached; the droplet shrinks due to evaporation and disappears. The voltage of the wire then returns to the initial level prior to interaction of the droplet.

Table 1.

Physical Properties of Water, Mineral Oil, and Malathion

<u>Property</u>	<u>Water</u>	<u>Mineral Oil **</u>	<u>Malathion***</u>
Density (gm/cm <sup>3</sup> )	1.0	0.838	1.232
Viscosity at 40° C (centipoise)	0.653	14.2 - 17.0	17.57
Surface Tension in air at 25° C (dyne/cm) *	66	28	34
Specific heat $\left( \frac{\text{cal}}{\text{cm}^3 \text{ } ^\circ\text{C}} \right)^{****}$	1.0	0.47	0.64

\* The surface tension for mineral oil and malathion was difficult to obtain from literature. Therefore a capillary tube experiment was used to obtain all of these values. The estimated experimental error is 20%. The published value for water is 71.97 dyne/cm.

\*\* Light grade of mineral oil supplied by Aldrich Chemical Co.

\*\*\* Cythion® is 91% malathion manufactured by American Cyanimid Co.

\*\*\*\* As with the case of the surface tension, the heat capacity of mineral oil and malathion was difficult to obtain from the literature and experiments were carried out to obtain such measurements. Water was used as a reference material to obtain an experimental constant. The estimated experimental error is approximately 20%.

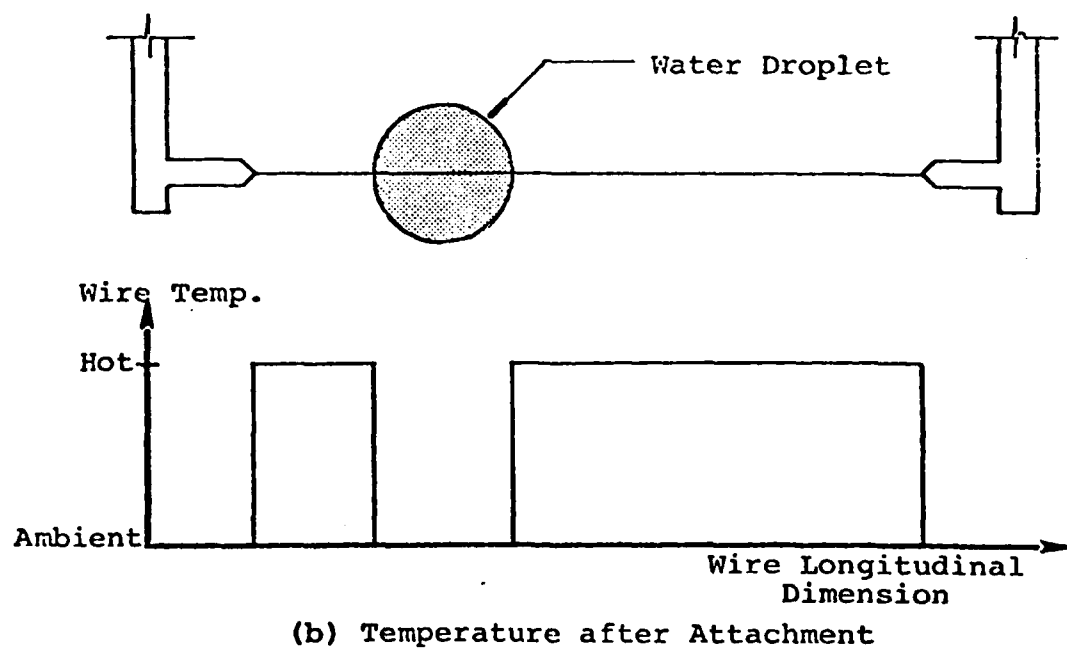
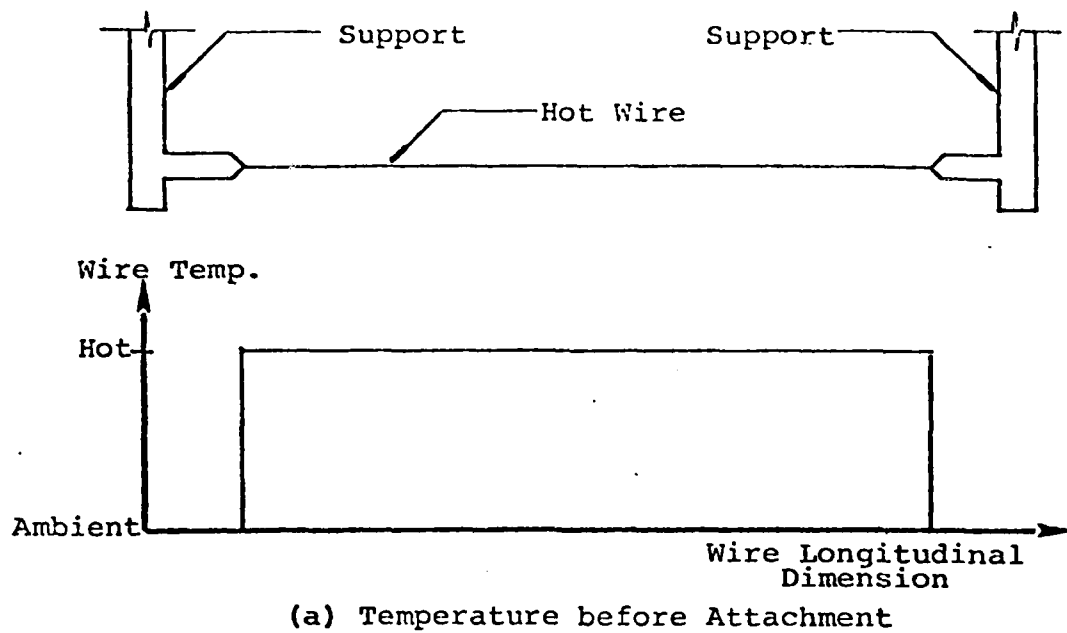


Figure 1. Principle of Operation of the Sensor

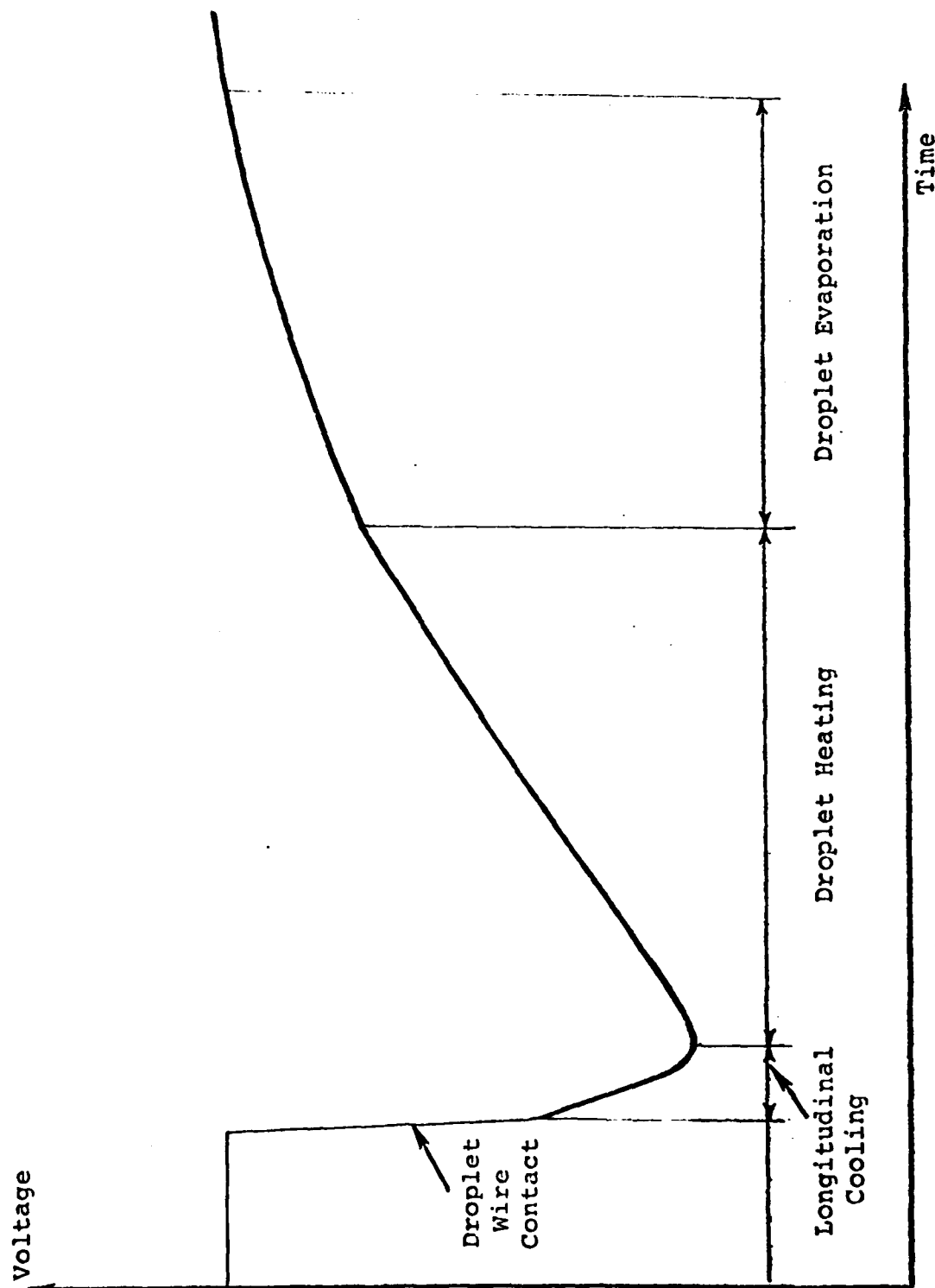


Figure 2. Electrical Signal from Sensor.

For the purpose of determining the droplet diameter, only the signal during the initial droplet contact is relevant and is processed. The processing is performed electronically, separating the initial portion of the signal and performing a frequency filtering. After the analysis of a droplet is started, the processor does not accept a second droplet for 2 msec. which allows the first droplet to fully evaporate and the hot-wire sensor to return to its proper operating temperature.

The calibration of the instrument (i.e., sensor output versus droplet diameter) is performed by simultaneously taking a microscopic picture of the droplet and measuring the corresponding electrical signal from the sensor (voltage drop). The apparatus for this purpose is described in Section 2.1. Various calibration curves may be obtained for different settings of operating conditions and signal processing; however, an optimum calibration is obtained as a compromise of the following conflicting requirements:

- One sensor and one operating temperature should cover the total droplet size range from 1  $\mu\text{m}$  to 450  $\mu\text{m}$ .
- The calibration curve should be monotonic.
- Air turbulence signals should not introduce false counting.
- The calibration curve should be independent of the droplet velocity relative to the sensor.

These requirements were achieved in the implementation of the DC-2A Droplet Counter; use in the field proved this approach to be sound.

## 2. LABORATORY TESTS

This section of the report describes a variety of laboratory tests used to evaluate the DC-2A as a device for measuring droplets of hydrocarbon materials (specifically mineral oil). In addition, a variety of effects have been studied to improve the calibration curve for the droplet measuring device. These latter tests are described in Sections 2.3, 2.4, and 2.6 of this report.

### 2.1 Apparatus for Size Calibration

This section describes apparatus which has been used to study the effects of eccentric collisions and mounting terminal collisions (Sections 2.3 and 2.4) and for calibrating the DC-2A with mineral oil and with water (Section 2.5). In addition, the apparatus is used to study the temperature stability of the hot-wire sensor (Section 2.6).

Figure 3 is a sketch of the apparatus used to simultaneously record a photograph of a droplet interacting with the wire and its corresponding electrical signal which the DC-2A uses for drop size analysis. Since the interaction time is short, an electronic flash is used to photograph the droplet/sensor contact within a microsecond of the initial interaction. Thus no appreciable evaporation of the droplet takes place. The flash duration is also approximately 4 microseconds. A high-speed Polaroid film (type 107) is used to record the photographic image.

In operation, the signal of the DC-2A is used to simultaneously trigger an oscilloscope and the electronic flash, in addition to triggering its own internal electronics. An oscilloscope camera is used to create a permanent record of the electronic pulse to be paired with the droplet photograph.

Figure 4 shows some examples of this data for several different sizes of mineral oil droplets. The magnification of the droplet photograph was determined by taking a picture of a calibrated microscope graticule. In Figure 4, the wire has a diameter of 5 microns.

### 2.2 Source of Monodisperse Droplets

Several techniques for the generation of monodisperse liquid particles have been used (6,7,8,9) by other investigators. In the past, KLD has developed and used several devices for droplet generation. In order to study the effects of eccentric collisions and the wire mounting terminals (Sections 2.3 and 2.4), an inexpensive device was devised to produce a nearly uniform supply of either water or mineral oil droplets.



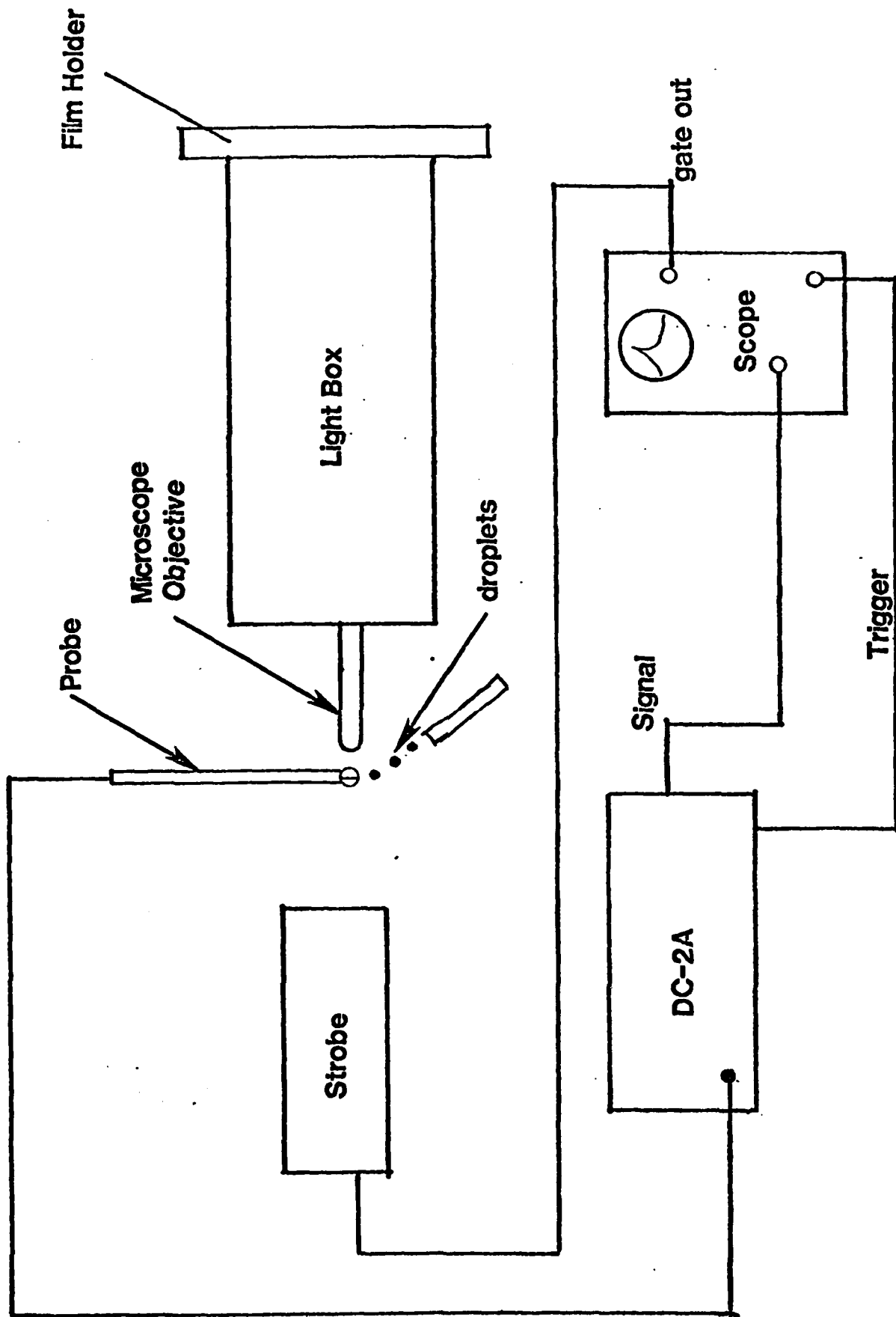
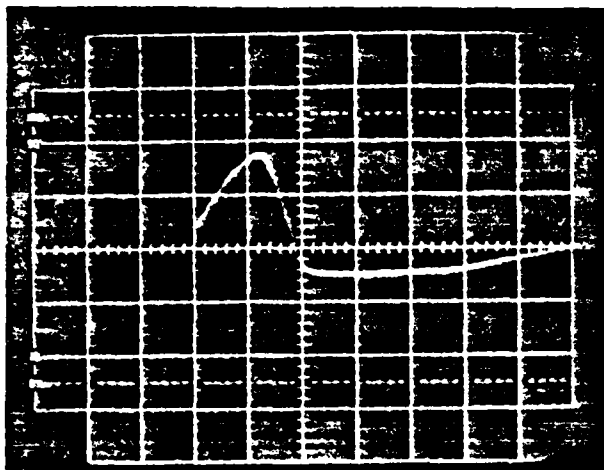
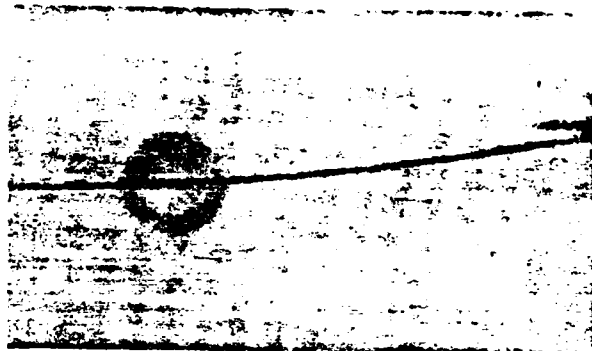


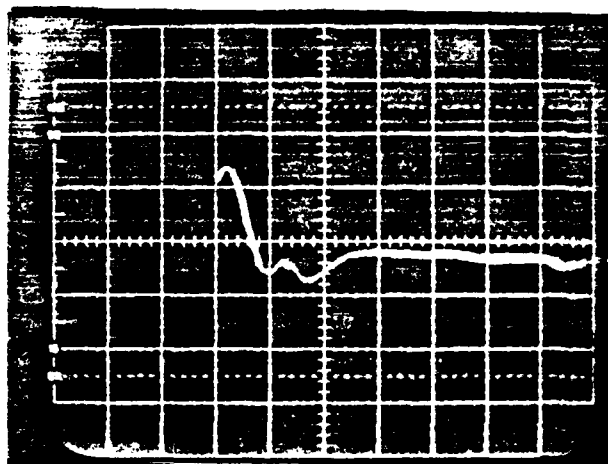
Figure 3. Droplet Calibration Apparatus



(a) 1 V/div., 10  $\mu$ sec/div.



98  $\mu$ m, water



(b) 50 mv/div., 5  $\mu$ sec/div.



24  $\mu$ m mineral oil

Figure 4. Sample calibration data for water (a) and mineral oil (b).

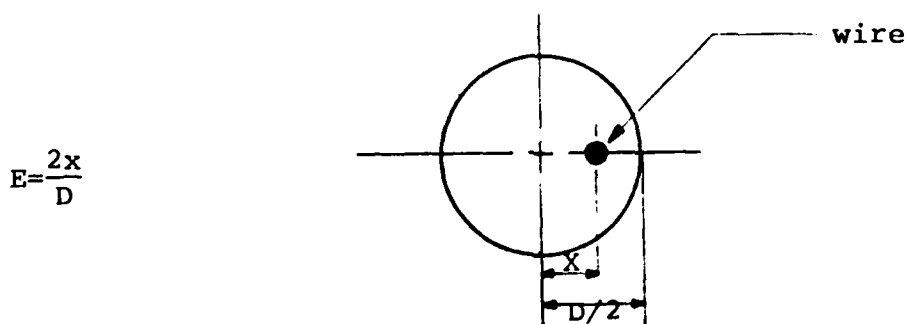
The apparatus developed is shown in Figure 5. A #27 gauge hypodermic needle is attached to a ferromagnetic spring which is driven by an electromagnet. The electromagnet, in turn, is driven by a frequency generator. The system works best when in resonance which occurs at a frequency of approximately 200 Hz. The amplitude of the vibration used was approximately 1 cm. The hypodermic needle was attached to a small piece of flexible tubing which was, in turn, connected to the liquid reservoir. For best performance, it was found that the reservoir needed to be pressurized. For the case of the light grade of mineral oil (see Table 1), this required a pressure of 30 psi.

The droplet sizes obtained using this technique were in the size range of 200 to 400 microns. Once the equipment was set up and running, the droplet size remained stable. No attempt was made to measure the variation in the particle size distribution for a defined operating condition. The apparatus was mounted on an XYZ micropositioner so that the droplet stream could be moved relative to the DC-2A probe which was held fixed relative to a microscope objective.

### 2.3 Effects of Eccentric Collisions

A frequently asked question is, "What is the effect when a droplet grazes the wire?" In prior studies with water, KLD demonstrated that surface tension very quickly centers the droplet around the wire.

Figure 6 is a plot of the "probe signature" as a function of eccentricity. The probe signature is defined as the peak of the voltage pulse measured at the probe due to an interaction with a droplet. The eccentricity,  $E$ , is defined by the following sketch:



This expression for the eccentricity is normalized for all size droplets;  $E=0$  is for a centered collision and  $E=1$  for a collision which just grazes the wire. Using such a definition, data for different droplet sizes can be plotted on a single graph, as shown in Figure 6. As seen in this graph, the drop signal decreases by approximately 23% for  $E=1$  as compared with  $E=0$ . At  $E=.8$ , this decrease is only 11%.

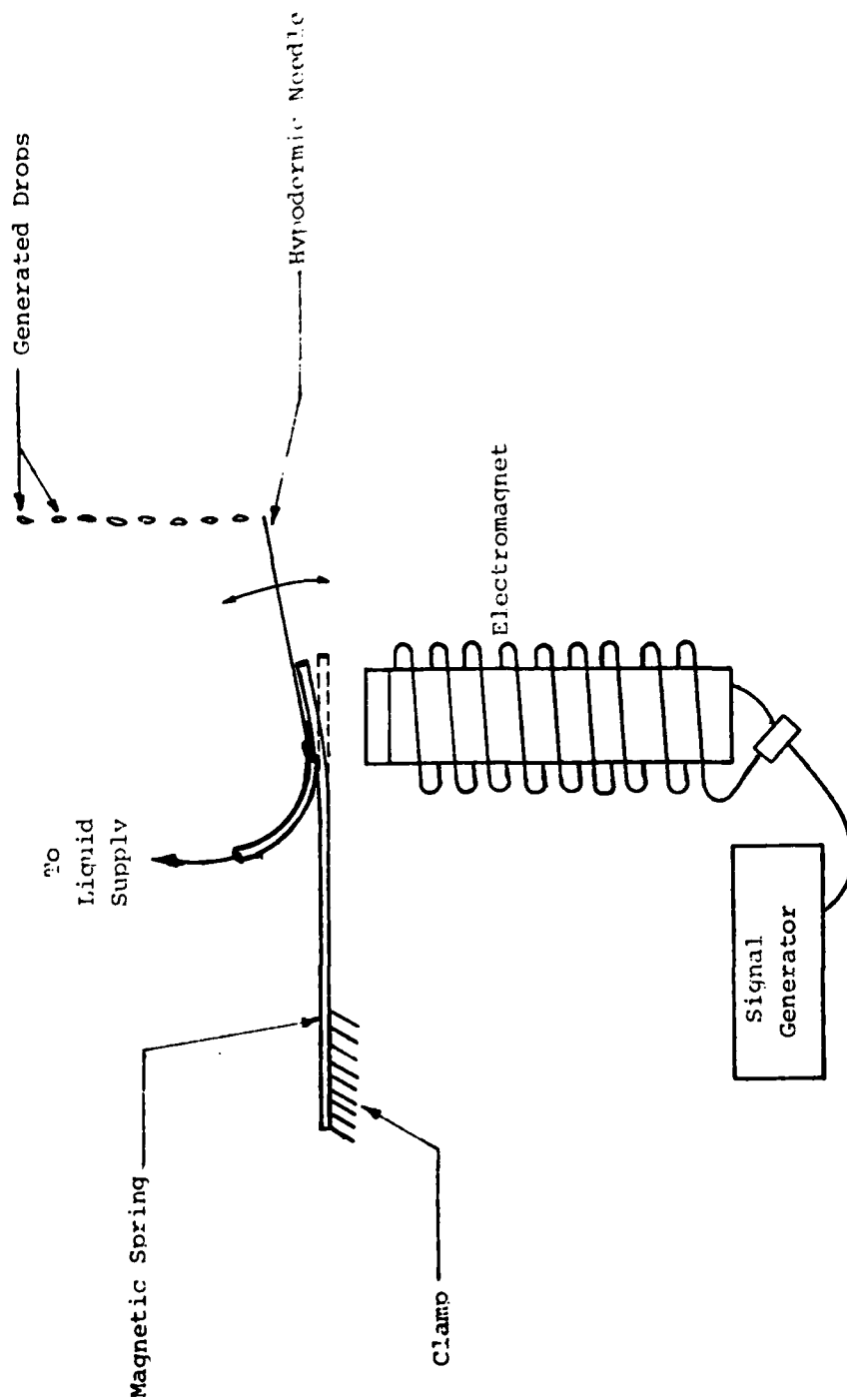


Figure 5. Apparatus for generating a monodisperse droplet distribution

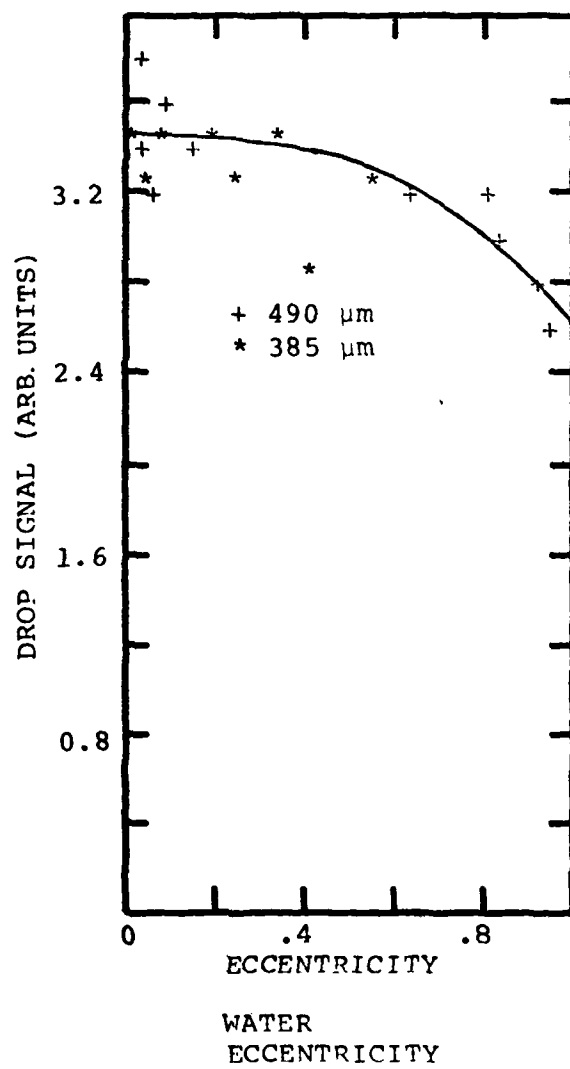


Figure 6. Eccentricity data for water

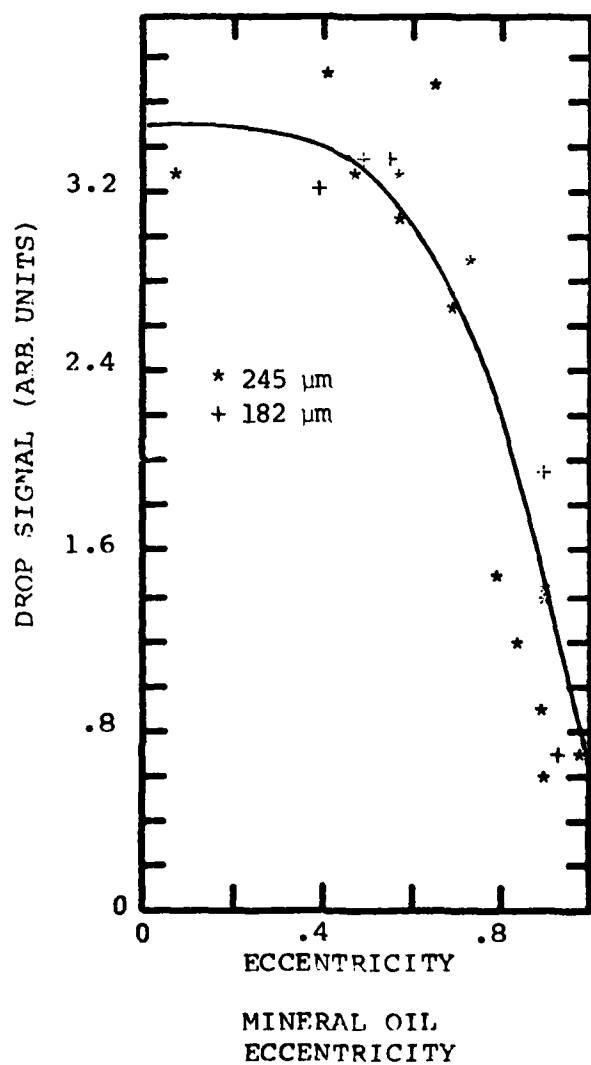


Figure 7. Eccentricity data for mineral oil

Only data for droplets striking the middle third of the wire sensor are shown in Figure 6, thereby eliminating the effects of the mounting terminals.

For the case of mineral oil, the effects of eccentric collisions are more pronounced. As seen in Table 1, the surface tension of mineral oil is less than half the surface tension of water. In fact, water has an unusually high surface tension compared to most organic and inorganic liquids. Figure 7 is the plot of the drop signals as a function of eccentricity for mineral oil. The maximum change in the drop signals due to eccentricity is approximately 81% (E=1) while the change at E=0.8 is 33%.

#### 2.4 Effects of Mounting Terminal

Based on the idealized model, the mounting terminals for the hot-wire have little or no effect on the droplet signal unless a droplet struck the wire in such a way that it was partly on the cool mounting post. Such a concept is shown in Figure 1(a) which shows a uniform temperature distribution along the entire length of the wire. This assumption was based on the fact that the ratio of the wire length to wire diameter is of the order of 200:1. However, this ratio is not large enough to insure that the longitudinal heat conduction is negligible. In fact, the heat conduction from the hot 5-micron wire to the cold mounting terminal is substantial. Assuming that the point of the wire support is at ambient temperature, the temperature distribution along the length of the wire (10) is given by:

$$\frac{T(z) - T_f}{T_\infty - T_f} = 1 - \frac{\cosh(z/\ell_c)}{\cosh(\ell/2\ell_c)}$$

where

$T(z)$  = temperature at any point along the wire

$T_f$  = temperature of wire support (same as ambient temperature)

$T_\infty$  = temperature of infinitely long wire with the same current

$z$  = position along the wire (see Fig. 8)

$\ell$  = wire length

$$\begin{aligned} \ell_c &= \text{cold length} \\ &= \frac{d}{2} \sqrt{\frac{R_w}{R_a} \frac{k_w}{k_f} \frac{1}{Nu}} \end{aligned}$$

where

$d$  = wire diameter

$R_w/R_a$  = ratio of hot-wire resistance to the wire  
resistance at ambient conditions

$k_w$  = thermal conductivity of platinum

$k_f$  = thermal conductivity of air

$Nu$  = Nusselt number

The "cold length,"  $\ell_c$ , is not actually related to the physical length of the wire, as shown in the above expression. This definition is based on the wire having a total resistance equal to that of a wire of length,  $1-2\ell_c$  at a temperature,  $T_\infty$ .

Figure 8 is a plot of  $\frac{T(z) - T_f}{T_\infty - T_f}$  versus  $z$  taken from Ref. 10. Thus, the temperature distribution along the length of the wire is not uniform as in the idealized model presented in Section 1.

Using the calibration apparatus and the generator of uniform droplets, data was taken and plotted as a function of the position along the wire,  $z$ . Such data is shown in Figure 9. This experiment was only performed using water, which requires only a small correction due to eccentricity (Fig. 6) as compared to mineral oil. Using the above equation and assuming the appropriate parameters for our equipment, a curve of  $(T-T_f)/(T_\infty-T_f)$  versus  $z$  can be overlayed onto this plot using an arbitrary scaling factor.



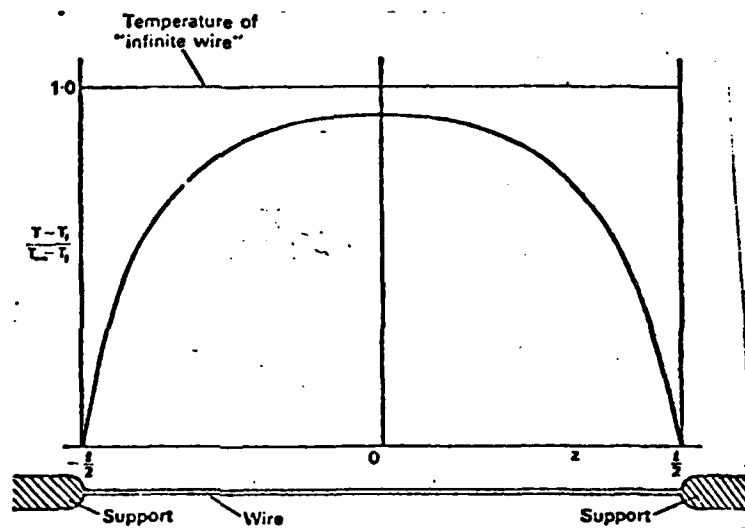


Figure 8. Effect of the supports on temperature distribution along the wire

The curve shown has been fitted to the data using a non-linear least-squares analysis (11). Such an analysis shows that the experimental data shown in Figure 9 approximates the theoretical temperature distribution along the wire reasonably well. The only details worth noting are that the wire temperature seems to be slightly higher in the middle and slightly cooler near the ends than predicted by this theoretical equation. For purposes of using the DC-2A to calculate droplet concentration in a gas, an effective probe length of the 0.6 mm should be used instead of the physical length of 0.8 mm. Since this data does appear to follow the temperature distribution, there was no need to duplicate this experiment using mineral oil.

Experimental measurements of the longitudinal temperature distribution exist (12) and our results agree for similar length to diameter ratios ( $l/d$ ). In order to approximate a constant longitudinal temperature distribution, one needs  $l/d = 600$ . Such a wire length (3 mm) would render the DC-2A probe extremely fragile for normal field applications.

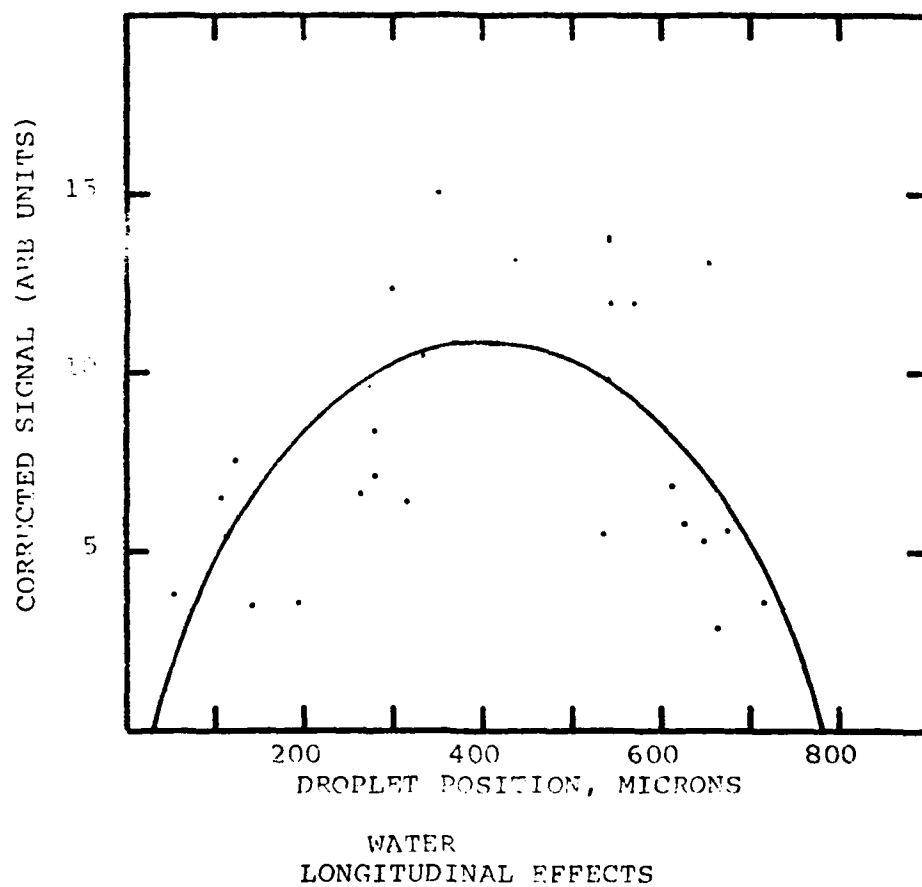


Figure 9. Effects of longitudinal wire position on the droplet signal

## 2.5 Instrument Calibration for Water and Mineral Oil

Figure 10 is a plot of the calibration curve for water (processed droplet signature in volts versus the droplet diameter in microns). Two sets of data were used to generate the graph. The first set was taken in August of 1980 when the DC-2A was initially fabricated. The second set was obtained under the present contract. Both sets of data confirmed the calibration curve in Figure 10 demonstrating stability of the DC-2A over a period of time. In total, Figure 10 represents nearly 100 data points. As shown by the error bars, a large amount of scatter is present. This scatter is mostly due to the effects of the temperature distribution along the wire (see Figure 9). The contribution of eccentric collisions to this scatter are relatively minor, since such collisions have relatively little effect on the drop signature (see Figure 6) for the case of water.

Figure 11 is a plot of the calibration curve for mineral oil. Over 100 points were used to develop this plot. An inset shows an enlarged plot of the curve for droplets smaller than 35 microns. Several significant differences can be noted when comparing the mineral oil data with the water data. These are listed as follows:

- Except for the very small droplets, the processed signals are significantly lower for mineral oil than for water.
- The slope of the calibration curve for mineral oil is smaller than for water. For mineral oil droplets larger than 240  $\mu\text{m}$ , the sensitivity of the instrumentation system is low (small changes in voltage for given change in droplet diameter). However, since insecticide sprays rarely have droplets exceeding 100  $\mu\text{m}$ , this result is not critical to the measurement requirements of the U.S. Army.
- The spread in the processed signal is less for mineral oil than for water. This spread, is due in part, to the fact that the calibration curve itself is always less for mineral oil than for water. However, the spread in the calibration curve for the case of mineral oil is more strongly influenced by eccentric collisions (Figure 7), as well as by the temperature distribution along the wire.

In summation, the incorporation of the effects due to eccentricity and the longitudinal, wire temperature distribution on the calibration curve is important. The degree of scatter in the data is real, and cannot be ignored. It is due to eccentric collisions, longitudinal effects and combinations of the two. All of these events occur statistically under real spray conditions, and it is

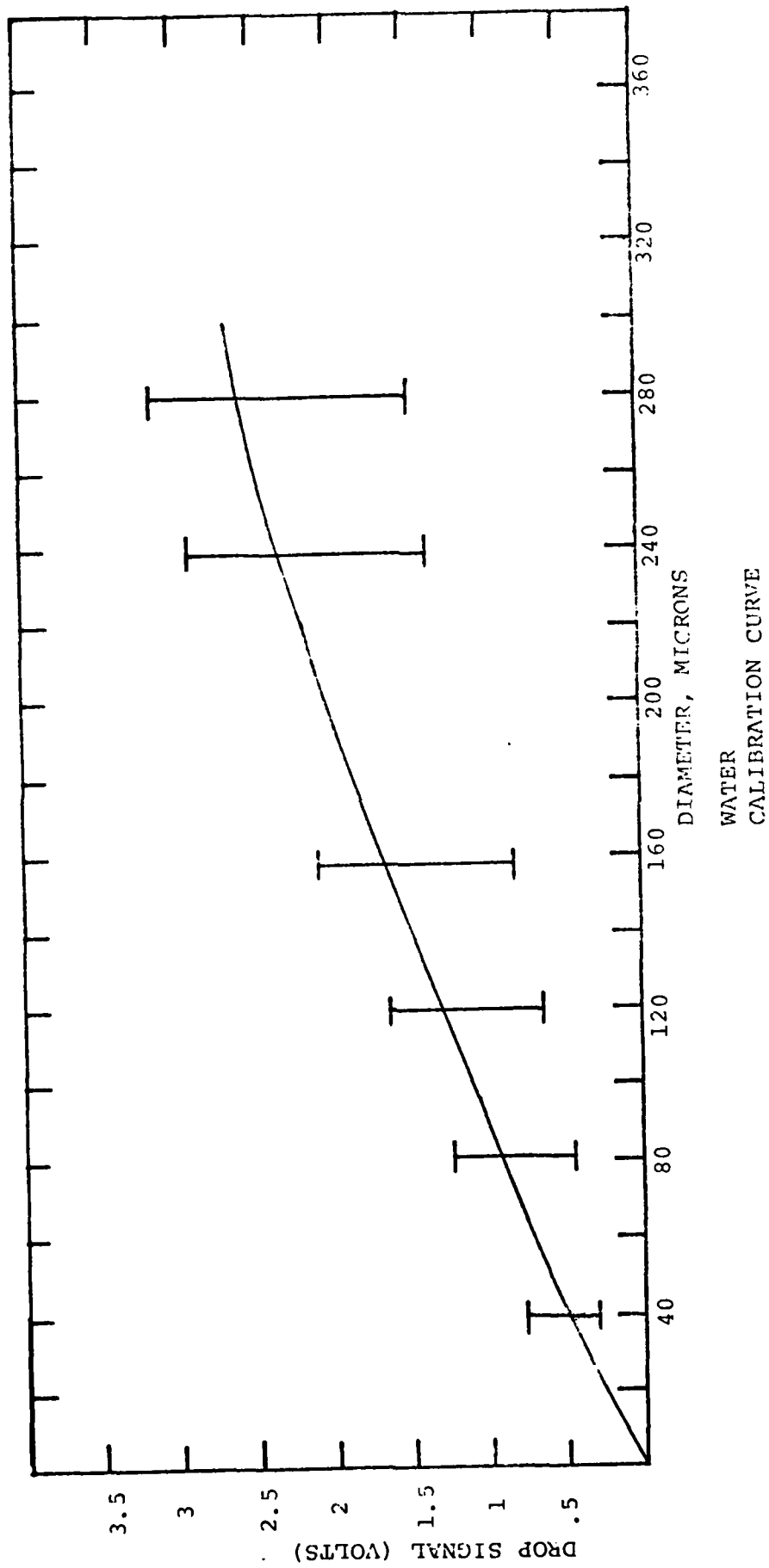


Figure 10. Calibration Curve for water

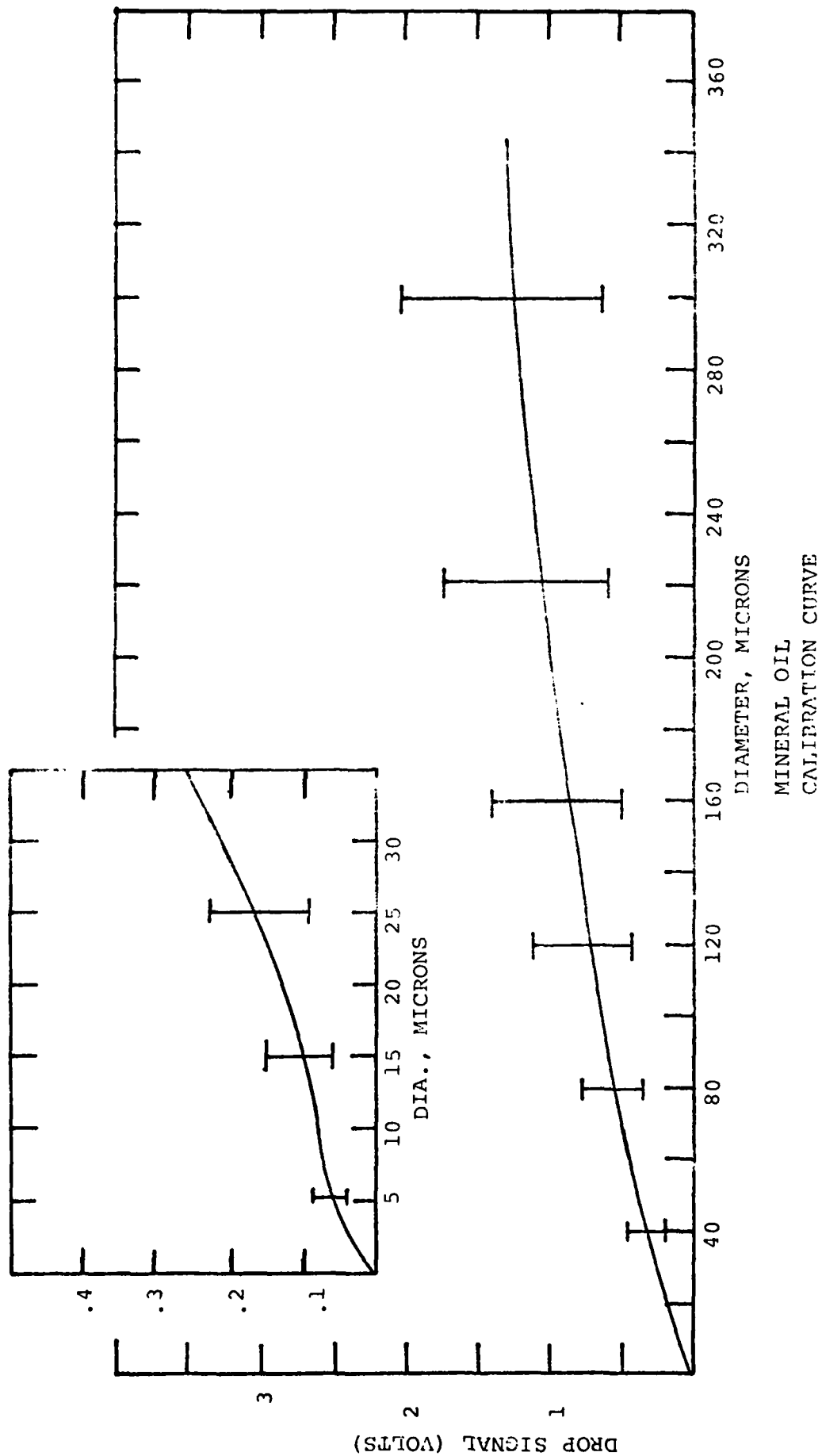


Figure 11. Calibration Curve for mineral oil

important that no data points be discarded because they may seem to be "extreme". The CALIBRATION CURVE is a line which must be selected from this array of points in such a way that it represents the best statistical line possible. Because of the scatter, it is important that as large a data sample be used as is reasonably practical.

## 2.6 Temperature Stability of the Wire Sensor

In operation, the DC-2A senses the ambient temperature by measuring the resistance of the "cold" probe. The probe is then heated so that its hot resistance is twice the value of the cold probe. When a droplet (at ambient temperature) interacts with the hot probe, the probe is cooled over a length equivalent to the drop diameter, causing the resistance to drop sharply and a voltage spike to be generated. This voltage spike is processed by the DC-2A in order to classify the size of the droplet. A feedback circuit is then used to quickly recover the initial temperature of the probe. Details of this interaction have been discussed in Section 1 of this report.

Although the droplet size is classified and stored very quickly ( $<10 \mu\text{sec}$ ), the probe takes much longer to be restored to its original overheat temperature. To take this unstabilized probe into account, a 2 msec blanking period is presently being used, and no additional data is collected during this period. For low and moderate counting rates (less than 200 drops per second), this procedure is adequate, but for higher counting rates there is the danger (see Figure 12) that a second droplet may strike the wire at perhaps 1.8 msec, and although drop #2 is not being counted the wire will not be stabilized when the blanking period is over. If a third droplet interacts with the wire soon thereafter, there is a strong possibility that its size may not be correctly interpreted. Although such situations also occur for low counting rates, they will statistically be far less significant than for high counting rates.

Measurements were made of the time duration to evaporate both water and mineral oil droplets. Naturally, the larger droplets cause the probe to have a longer recovery time. Sample times are:

300  $\mu\text{m}$  water: 2.5 msec  
300  $\mu\text{m}$  mineral oil: 2.0 msec.

Thus, the situation for mineral oil should be less critical than for water. An analytical explanation for the faster recovery time for mineral oil is expected to be complex. The heat transfer problem involved time/temperature variations in the film coefficients and droplet size. Other parameters expected to be involved are the

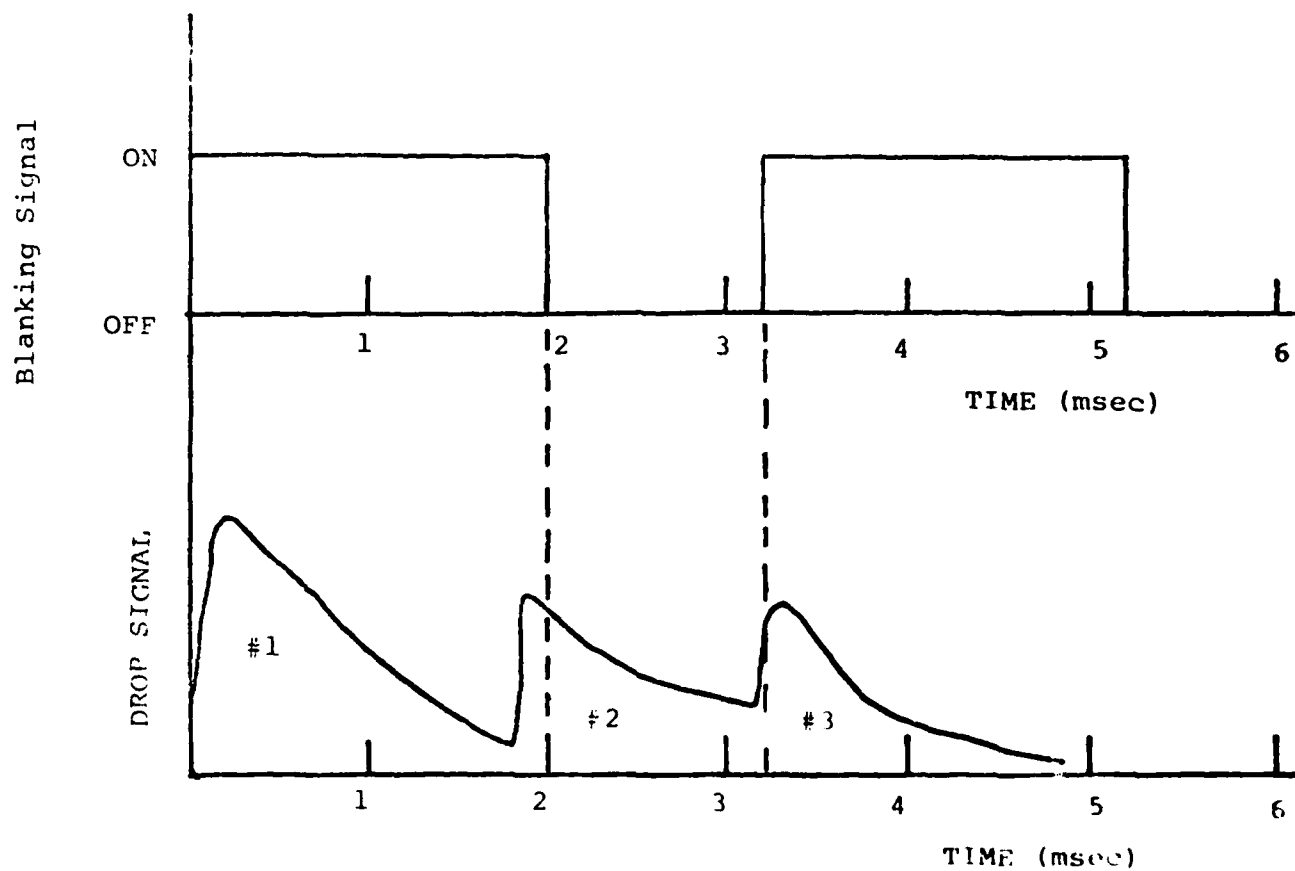


Figure 12. Illustration of the droplet signal for a sequence of droplet interactions. See text for discussion.



specific heats, latent heats, boiling points, and densities.

In order to enhance the performance of the DC-2A, a special inhibit circuit (Figure 13) was designed and tested. This circuit can be used to trigger a blanking circuit whenever the probe temperature is not stable. When no droplet is interacting with the probe, the bridge is balanced and points (a) and (b) are at the same potential. Under these conditions, both legs of the inhibit circuit are the same and there is no output to the blanking circuit. When a droplet strikes the probe, unbalancing the bridge, the two legs of the inhibit circuit are not the same and a signal is relayed to the blanking circuit. The gain of this inhibit circuit can be adjusted to meet whatever threshold level is desired. A zener diode is used to keep the output of the inhibit circuit below 5 volts to protect the digital logic of the blanking circuit. As tested, an overall gain of 500 was used. Tests showed that the circuit as designed was "turning on" for drops larger than 70  $\mu\text{m}$ . Tests were performed with a spray having a large number of droplets above 70  $\mu\text{m}$  and at a counting rate approaching the maximum performance of the DC-2A (nearly 500 drops/sec). The output of the inhibit circuit was not interfaced with the blanking circuit for these tests, but was merely being monitored with an oscilloscope. Even at these extreme conditions it was noted that while the inhibit circuit was being turned on and off quite rapidly, it was rarely on for longer than 2 msec at any one time. Thus, the advantages to be gained by incorporating an inhibit circuit into the design of the DC-2A is not considered highly beneficial for these applications.

## 2.7 Contamination of the Sensor

It is well known that certain aqueous solutions will coat the sensor wire, thereby degrading its sensitivity. Some materials, such as sodium chloride, will coat the probe, but are easily cleaned by a short soak in clean water or by running the probe cold in the gas/droplet mixture. Other solutes, such as limestone, will quickly render the probe unusable and are then difficult, if not impossible, to clean. Each material used must be investigated separately.

Materials other than water must also be considered with respect to possible degradation of the probe. A study of two classes of materials are being presented in this section: mineral oil, and a variety of less refined oils.

For the case of mineral oil, no degradation in probe sensitivity was noted after 250 runs over a period of two days. Each run consisted of using a given spray until 10,000 drops were counted. Table 2 is a listing of the pertinent data showing the average and standard deviation of the first five runs and the

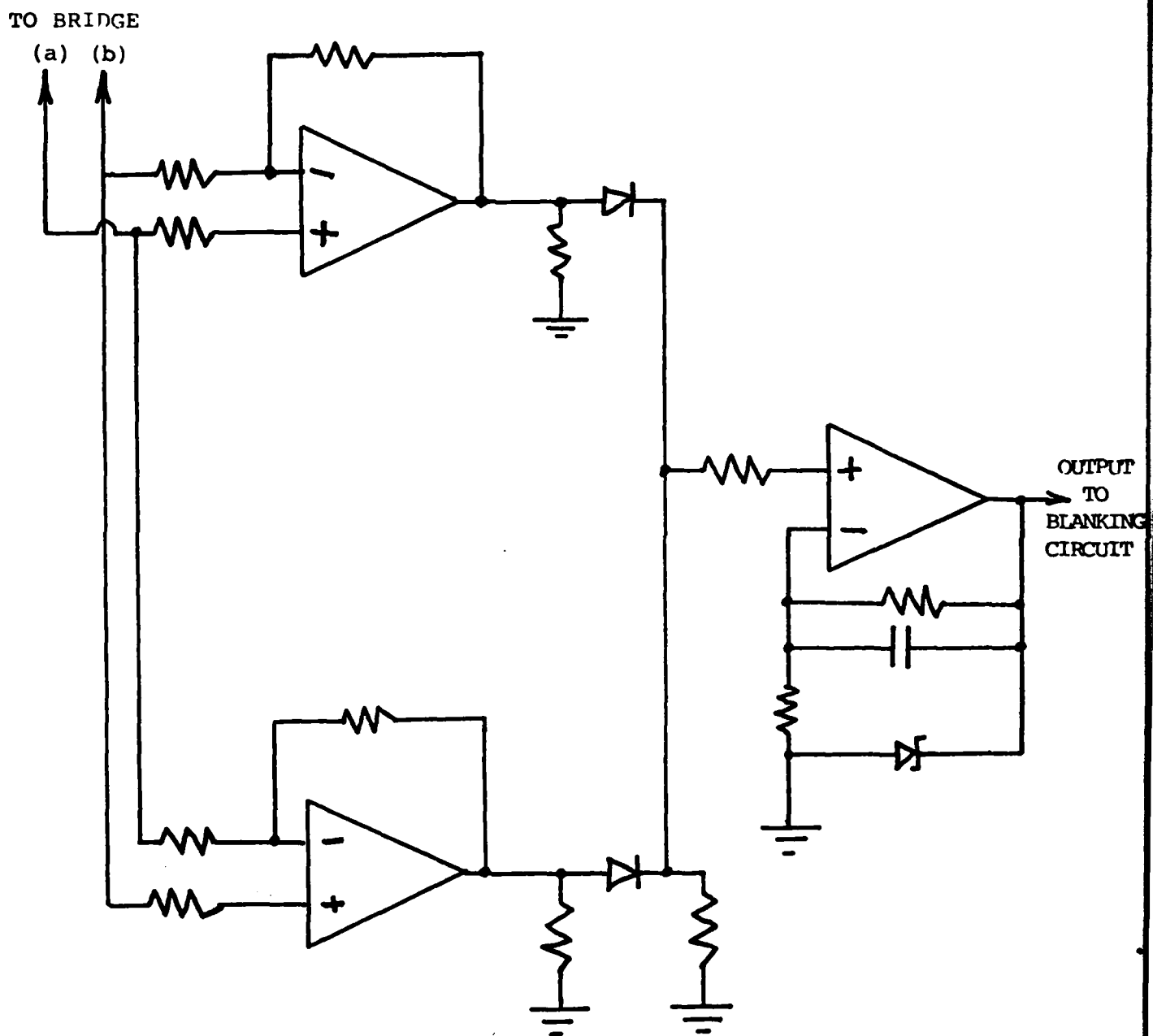


Figure 13. Inhibit Circuit

Table 2

	AV. RUN 1-5			AV. RUN 246-250			COMPARISON AVERAGE		
BIN 1	4757	±	4%	4664	±	1%	4710	±	1%
2	2565	±	2%	2360	±	1%	2462	±	6%
3	528	±	2%	529	±	2%	528	±	.1%
4	439	±	11%	433	±	5%	436	±	1%
5	463	±	6%	493	±	4%	478	±	4%
6	472	±	10%	504	±	3%	488	±	5%
7	514	±	8%	618	±	4%	566	±	13%
8	213	±	14%	318	±	5%	266	±	28%
9	32	±	31%	51	±	16%	42	±	32%
10	12	±	17%	23	±	30%	18	±	44%
11	5	±	20%	6	±	33%	5.5	±	13%
12	1	±	100%	0			0.5	±	141%
13	0			1	±	100%	0.5	±	141%
14	0			0			0		
TOTAL	10000			10000			10000		
TIME (SEC)	179	±	3%	182	±	0	181	±	1%
VEL.	10			11			10.5	±	7%
TEST	25			31			28	±	15%
VmD (μm)	26			32			29	±	15%

last five runs in this sequence. The last column is a comparison of these two averages. As seen, the results are very repeatable when enough droplets are counted to be statistically meaningful. The volume median diameter (VMD) is also very repeatable. In addition, Figure 14 shows microphotographs of the sensor wire taken before the spraying started (a) and after the entire series of test runs (b). As can be seen, no noticeable coating has accumulated on the wire.

During a second two-day series of tests, three different spray nozzles and approximately six different oils were tested. A single probe was used for most of the first day of testing. After measuring oil sprays for over two hours, a noticeable degradation in the data was observed. A second probe was used and the performance of the DC-2A returned to that of the initial tests. The original probe was examined under a microscope and a definite coating of what appeared to be cracked oil was observed. This probe was restored to its initial state by immersing it in commercial engine cleaner (e.g. "GUNK") for 48 hours. After rinsing with tap water, the original sensitivity of this probe was restored. It is felt that the 48 hour soaking of the probe could be greatly reduced with the use of stirred engine cleaner. Such tests were not carried out.

Thus, it was shown that highly refined oils, such as mineral oil, leave little or no residue on the sensor in comparison to less refined oils such as hydraulic and machine oils.

## 2.8 Assessment of Instrument Accuracy

On March 29, 1983, comparison tests were made at the Aberdeen Proving Grounds. In attendance from Fort Detrick were Major Phillip Pierce (COTR), Dr. Richard O'Conner, Dr. James Nelson, and two technicians. Representing KLD Associates were Dr. David Mahler (PI) and Mr. Lawrence Danziger (technician). It was decided by Major Pierce that a "Slide Wave" technique would be used in place of the Optical Image Device (OID) which was inoperable.

The comparison tests were conducted at Aberdeen Proving Grounds because large indoor wind tunnel facilities were available. An indoor facility was necessary because, at this time of year, outdoor temperatures are lower than the temperature range required to use the slide wave technique. Fort Detrick does not have the indoor facilities needed to safely operate large sprayers with insecticides.

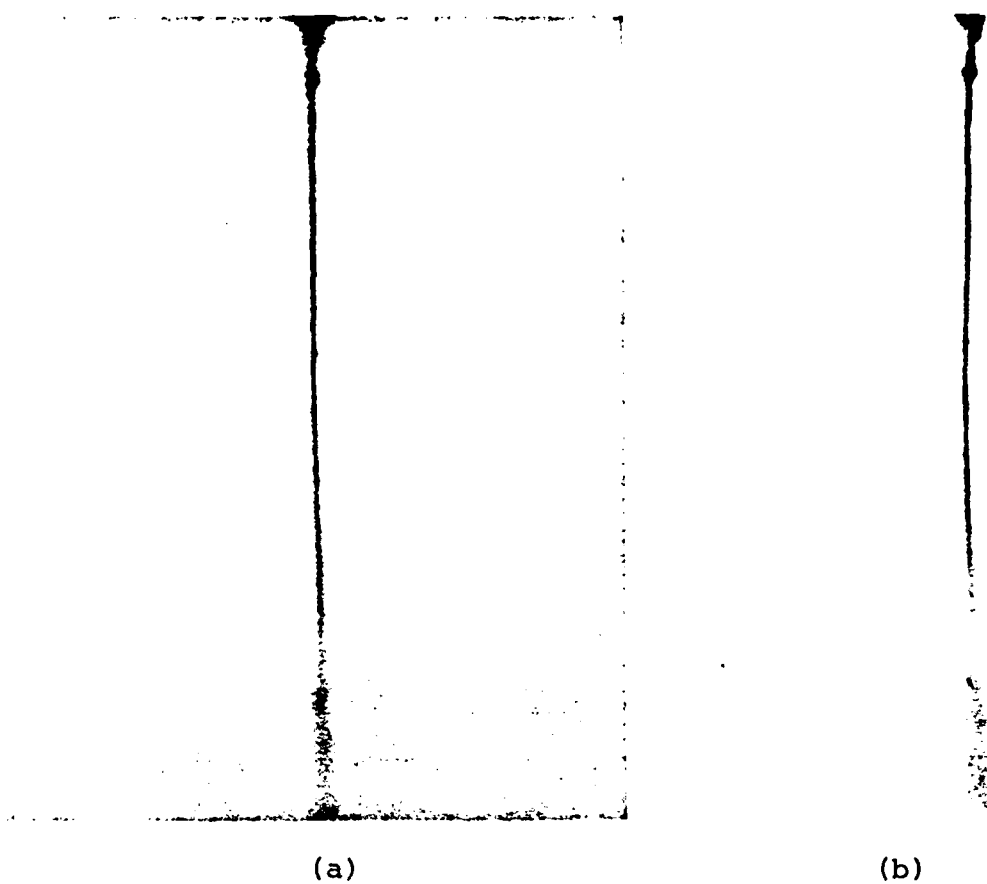


Figure 14. Sensor wire before (a) and after (b) being bombarded by  $2.5 \times 10^6$  mineral oil droplets over a period of two days.

Table 3 illustrates the results which were obtained for this series of tests. The last two columns compare the volume median diameter (VMD) as measured with the DC-2A with the slide wave analysis. Six tests were made using four different sprayers and three different liquids. The raw data and curves showing the percent cumulative volume versus particle size appear in Appendix A.

Several observations can be noted from Table 3.

- For tests 1-4, the DC-2A consistently produced a VMD which averaged about 17% higher than the VMD obtained for the slide wave analysis.
- Tests 5 and 6 are not considered as reliable as tests 1-4 because of the poor statistical sample obtained. In order to obtain better statistics, it would have been necessary for data to be taken for a longer period of time. If the DC-2A had been allowed to accumulate data for 1,000 seconds, the sampling would have proved adequate. However, the technician operating the Fox and Sprite sprayers could not maintain the orientation of these sprayers for that period of time. Despite the poor statistical sample, reasonable values of the VMD were obtained. Both the DC-2A and slide wave showed that the Sprite and Fox sprayers had VMD's significantly higher than the LECO and CCG-1 sprayers.
- The results obtained using Dow Mosquito Concentrate (DMC) and cythion compare well using the calibration curve obtained for mineral oil. This observation is encouraging with respect to Section 1.2 and Table 1 where mineral oil and cythion (91% malathion) are shown to have similar surface tension and viscosities. Though values of these parameters are not available for DMC, the VMD results indicate that this same calibration curve would apply.

Although the DC-2A and slide wave results compare well and are extremely encouraging, several features of the slide wave approach should be noted. Factors affecting the slide wave results include: the condition of the slide, the manner in which the slide is passed through the spray, and the individual who analyzes the slide. In addition, it should be mentioned that the slide wave averages data over a large cross-section of the spray pattern in a short period of time, while the DC-2A averages data over a relatively long period of time in a small cross-section of the spray pattern.

Table 3

## DC-2A/Slide Wave Comparisons

<u>Test</u>	<u>Sprayer</u>	<u>Liquid</u>	<u>VmD</u>	
			<u>(DC-2A)</u>	<u>Slide Wave</u>
1	LECO at 30 ml/min	Mineral Oil	15.5	12.5
2	LECO at 30 ml/min	Dow Mosquito Concentrate	8.0	7.8 <sup>1</sup> , 7.5, 6.5
3	CCG-1	Mineral Oil	18.7	16.2
4	CCG-1	Cythion	19.7	17.4
5	Fox at 5 ml/min	Cythion	28.2	33.4
6	Sprite at 5 ml/min	Cythion	26.7	42.5

<sup>1</sup>Three slide waves were measured with this configuration. The first number 7.8  $\mu$ m were measured at the same time the DC-2A was collecting data. The other two numbers were obtained at different times.

### 3. CONCLUSIONS

All six tasks of the research project were completed and the results are extremely encouraging. Based upon the mineral oil results, the concept used in the DC-2A is transferrable to a specialized device to be used by U.S. Army personnel for droplet size measurement of insecticide and herbicide sprays. The following questions raised in the Phase I proposal have been satisfactorily answered.

1. The effects of eccentric collisions and longitudinal position (post effects) on droplet/wire interactions are important, but can be handled by proper statistical use of calibration data in order to generate a calibration curve.
2. It has been shown that the temperature stability of the probe is achieved using the 2 msec delay presently incorporated in the DC-2A. A special circuit which monitors the probe temperature is not necessary.
3. Probe contamination is definitely not a problem for mineral oil, although it is not to be ignored for less refined oils. No spray tests were performed using insecticides to assess their contamination properties. Experiments relevant to contamination caused by insecticides are discussed in the Phase II proposal.
4. A calibration curve has been generated for mineral oil and implemented in the electronics of the DC-2A. Although it has yet to be shown that the mineral oil calibration curve is transferrable to all insecticides of interest to the Army, it has been demonstrated that physical properties believed to be relevant to the calibration are similar for both malathion and mineral oil. Specifically, the surface tension of mineral oil is close to that of malathion, but significantly different in comparison to water. It is desirable to have a single calibration curve for all insecticides of interest to the U.S. Army. This issue will be addressed in the Phase II proposal.
5. Tests have shown that the calibration curve generated for mineral oil is usable for at least two insecticides of interest to the Army, cythion (malathion) and Dow Mosquito Fog Concentrate (DMC). These results are based on comparison of data simultaneously taken with the DC-2A calibrated for mineral oil and slide wave analysis.



The results of the Phase I effort indicate that an instrument using hot-wire technology can be developed to meet the needs of the U.S. Army for measuring the droplet size distribution of insecticide and herbicide sprays. Such an instrument will be compact, rugged, field portable, and capable of being used by typical enlisted personnel.

A Phase II proposal has been prepared in which a major emphasis is directed towards developing calibration curves for those insecticides of interest to the U.S. Army. It has already been demonstrated that a single calibration curve can successfully be used for cythion and DMC. Hopefully the results will show that a single calibration curve can be used with a larger variety of insecticides. If a single calibration curve is not possible, methods of using a single instrument are suggested. The remaining Phase II proposal consists of: designing and building a prototype instrument specifically designed for use by military personnel involved in pesticide spraying; and for investigating the feasibility of using hot-wire instrumentation for the detection of submicron droplets.

Appendix A  
DC-2A Data

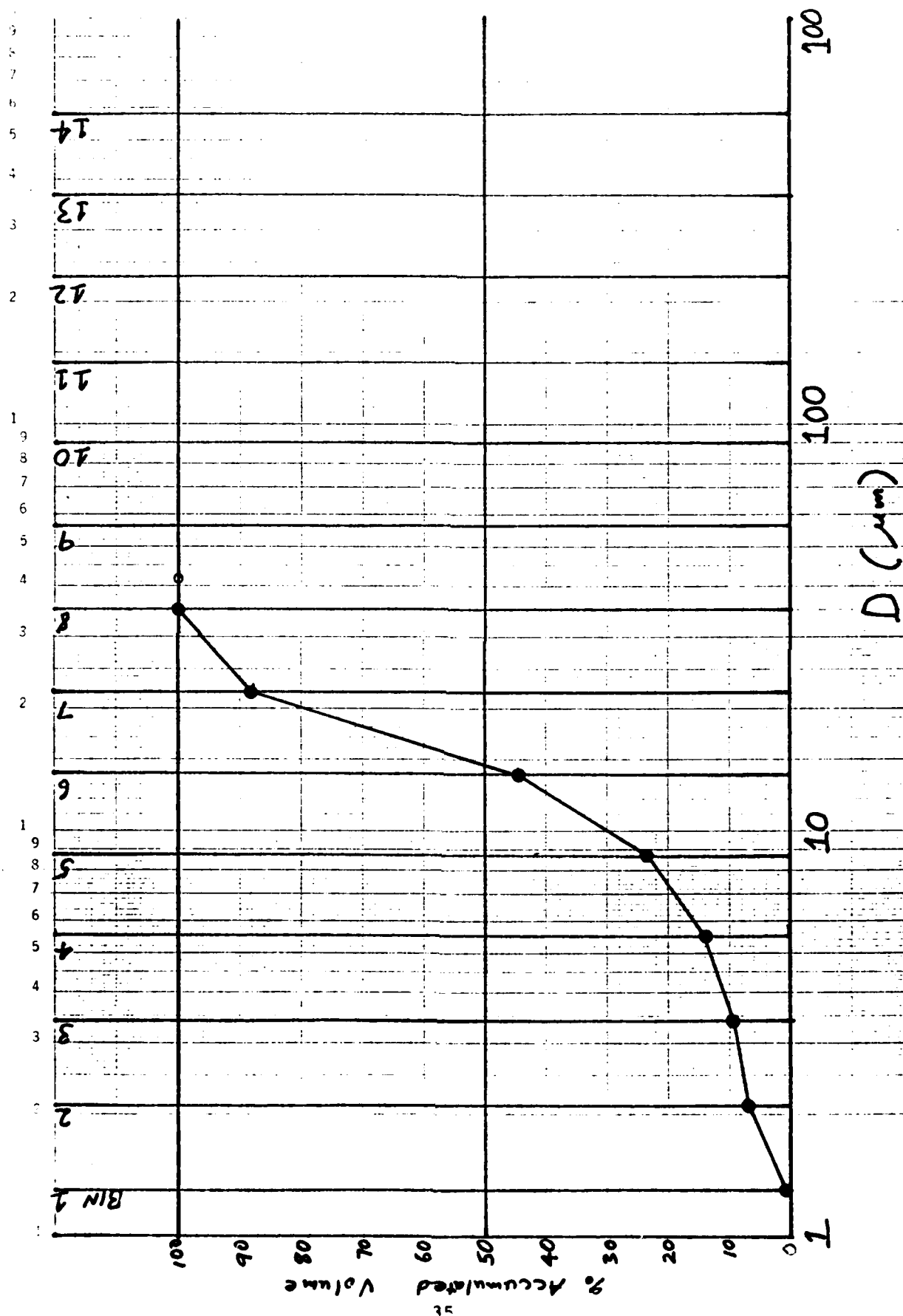
DC-2A data, corrected data and percent  
accumulated volume. Plots of percent  
accumulated volume versus droplet diameter.

Test : 1

Sprayer: Leco, 30 ml/min.

Liquid : Mineral Oil

Bin (i)	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% v_{ij}$
1	5095	25475	3.43
2	2528	7078	6.91
3	684	1368	9.25
4	512	819	13.87
5	467	560	23.78
6	393	393	44.42
7	292	292	88.07
8	29	29	100.00
9			
10			
11			
12			
13			
14			
TOTAL	10000	-	-
TIME	334.80		-

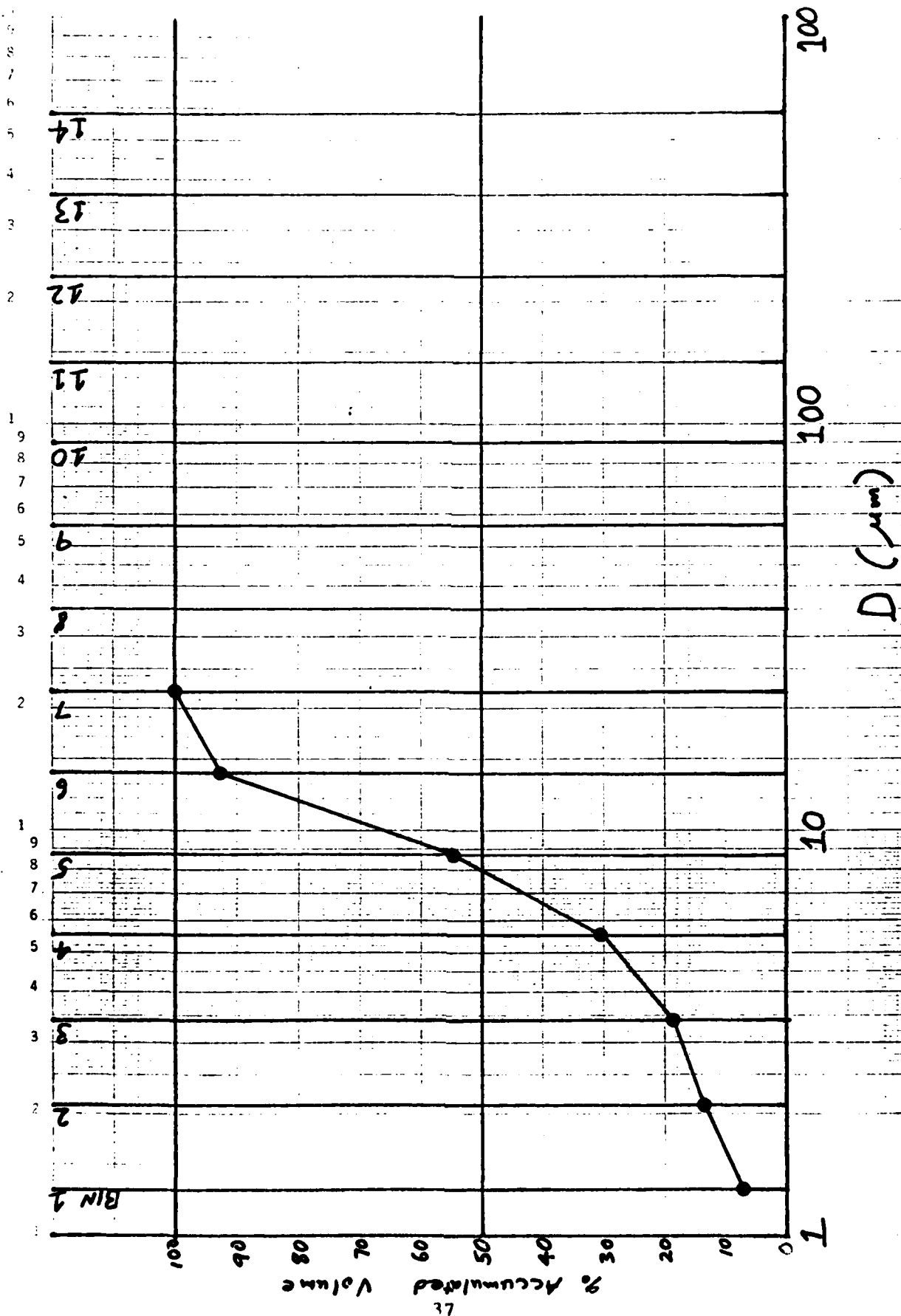


Test : 2

Sprayer: Leco, 30 ml/min.

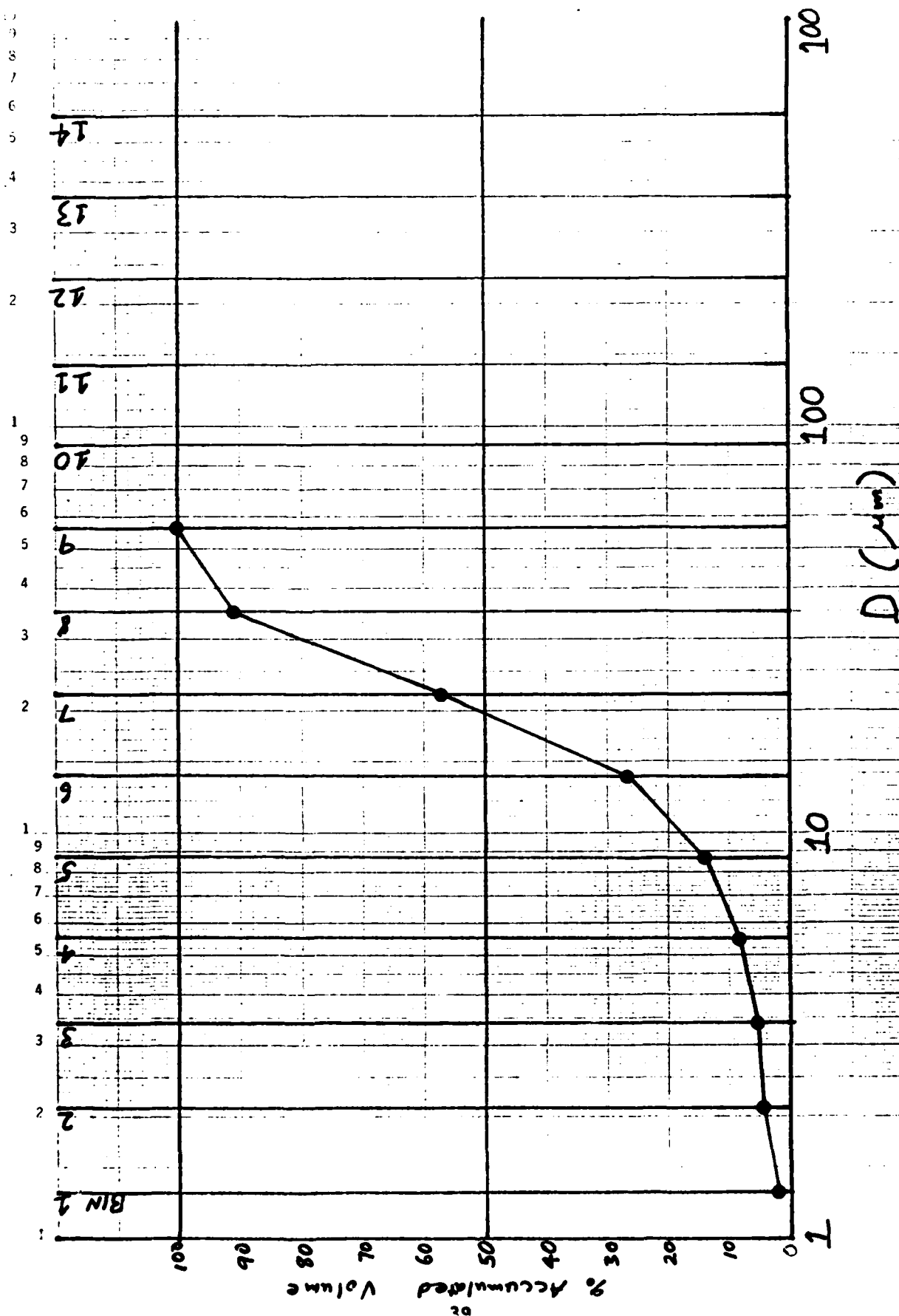
Liquid : Dow Mosquito Concentrate

Bin	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% V_{ij}$
1	1326	6630	6.72
2	672	1882	13.68
3	189	378	18.54
4	171	274	30.17
5	155	186	54.91
6	97	97	93.25
7	6	6	100.00
8			
9			
10			
11			
12			
13			
14			
TOTAL	2616	-	-
TIME	100.0		-



Test : 3  
 Sprayer: CCG-1  
 Liquid : Mineral Oil

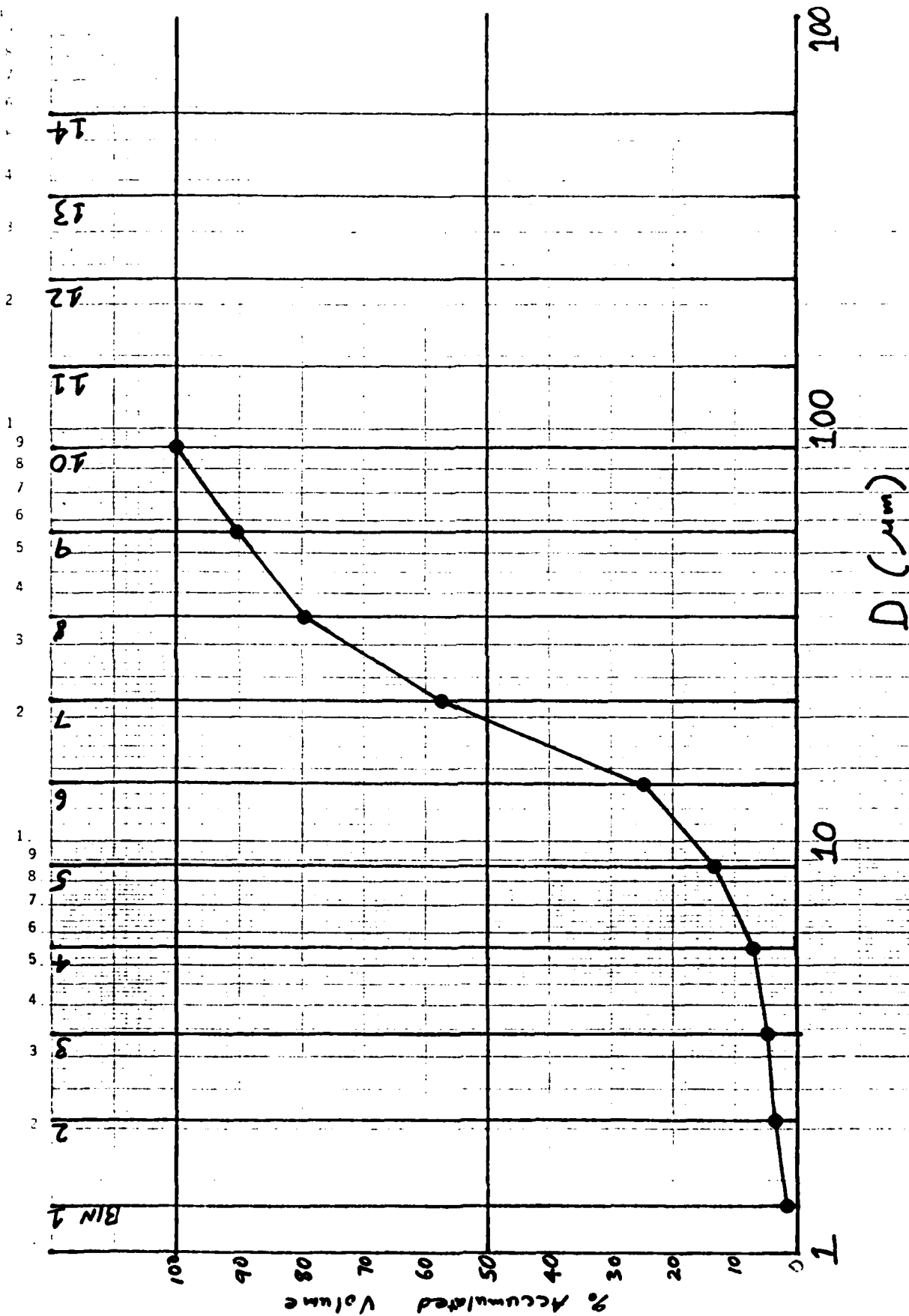
Bin	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% v_{ij}$
1	1141	5705	2.08
2	606	1697	4.34
3	124	248	5.49
4	107	171	8.11
5	101	121	13.92
6	90	90	26.74
7	76	76	57.54
8	30	30	91.01
9	3	3	100.00
10			
11			
12			
13			
14			
TOTAL	2278	-	-
TIME	100.0		-





Test : 4  
 Sprayer: CCG-1  
 Liquid : Cythion

Bin	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% v_{ij}$
1	797	3985	1.77
2	404	1131	3.59
3	97	194	4.68
4	81	130	7.09
5	92	110	13.51
6	63	63	24.39
7	68	68	57.83
8	16	16	79.49
9	3	3	90.40
10	1	1	100.00
11			
12			
13			
14			
TOTAL	1622	-	-
TIME	100.0		-

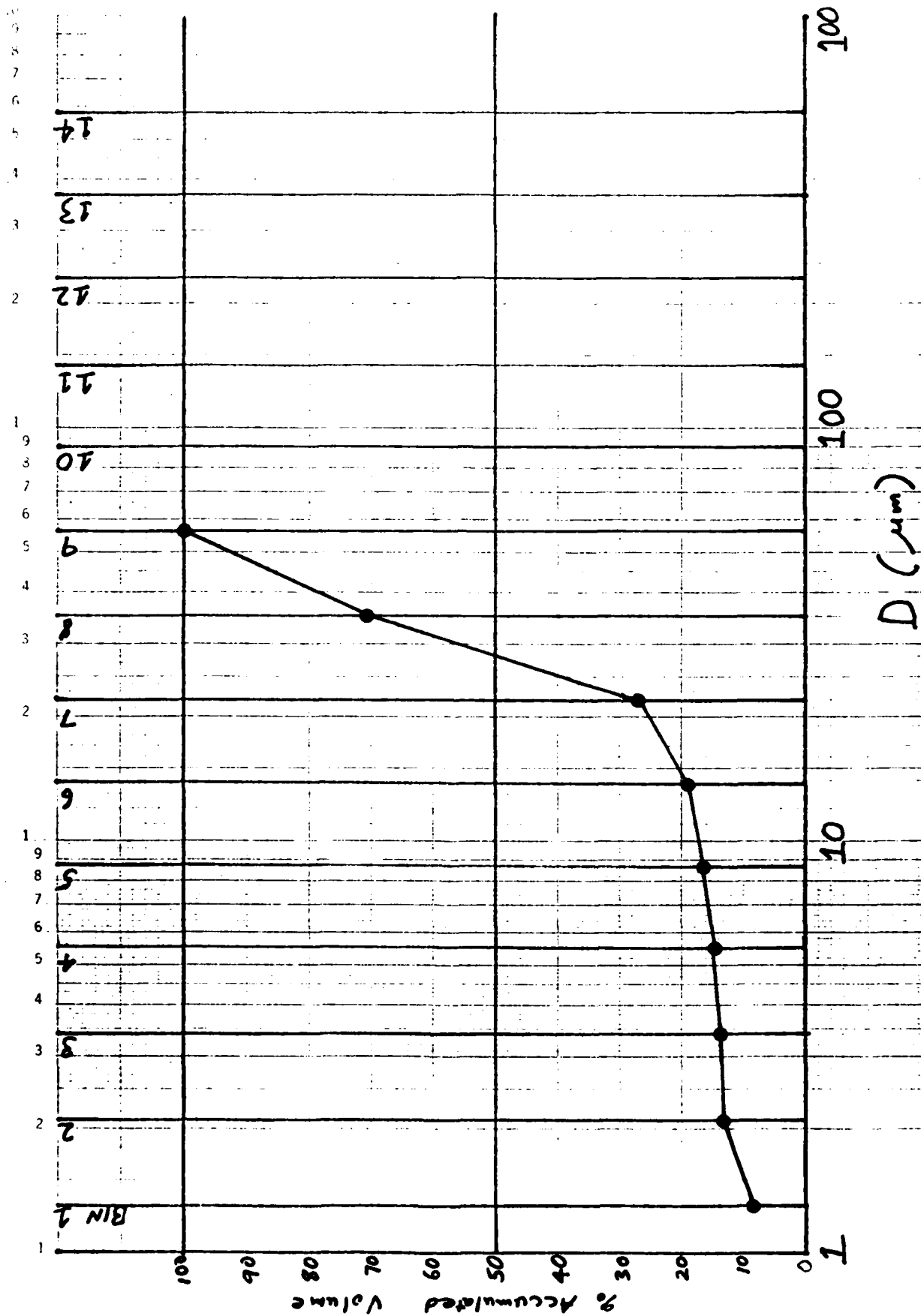


Test : 5

Sprayer: Fox, 5 ml/min.

Liquid : Cythion

Bin	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% V_{ij}$
1	481	2405	8.59
2	119	333	12.92
3	9	18	13.74
4	4	6.4	14.70
5	3	3.6	16.38
6	2	2	19.17
7	2	2	27.09
8	4	4	70.71
9	1	1	100.00
10			
11			
12			
13			
14			
TOTAL	625	-	-
TIME	100.0		-

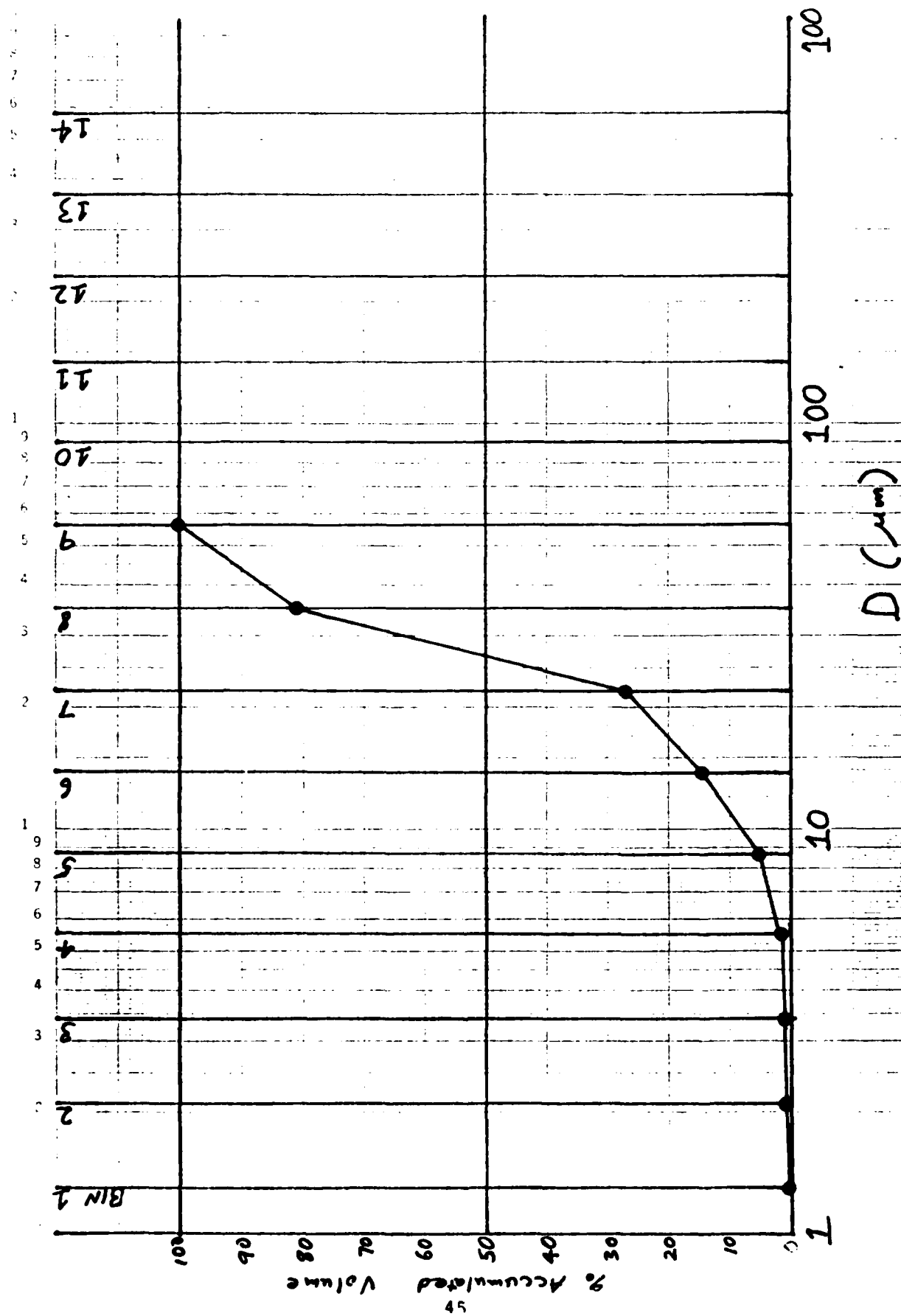


Test : 6

Sprayer: Sprite, 5 ml/min.

Liquid : Cythion

Bin	$N_i$	$K_i N_i$	$\sum_{i=1}^{14} \sum_{j=1}^i \% V_{ij}$
1	70	350	0.78
2	18	50	1.19
3	3	6	1.36
4	3	4.8	1.81
5	9	10.8	4.98
6	11	11	14.58
7	5	5	26.99
8	8	8	81.65
9	1	1	100.00
10			
11			
12			
13			
14			
TOTAL	128	-	-
TIME	100.0		-



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