LIQUID ATOMIZATION RELATED TO THE PRODUCTION AND MEASUREMENT OF SPRAY PARTICLES

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PREFACE

The work reported in this investigation was performed under Project 1146 of the Oklahoma Agricultural Experiment Station, "The Control of Woody Species in the Southern Plains". One of the objectives of this project concerned the engineering aspects of effective chemical application, the work being centered largely around the mechanics of particle formation and particle behavior. A related project, "Drift Control of Pesticides" has recently been approved. The equipment and techniques developed as a part of this thesis will provide the basic tools for continuing work on these projects.

I am especially grateful to Professor Jay G. Porterfield, who consented to serve as my thesis advisor, for his advice and continued encouragement throughout the program of study.

I wish to thank Professor E. W. Schroeder, Head of the Agricultural Engineering Department; Dr. Gordon L. Nelson of the Agricultural Engineering Department; Dr. Carl E. Marshall of the Department of Mathematics and Statistics; and Dr. O. H. Hamilton of the Department of Mathematics and Statistics for serving on the advisory committee.

To all others (and there were many) who assisted directly or indirectly in this investigation, I express sincere appreciation.

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CHAPTER I

INTRODUCTION

Liquid atomization is an important process in many industries. Among the more important applications are:

1. Fuel atomization for furnaces and engines.
2. Atomization in industrial processes such as spray drying, humidifying, cooling, and air conditioning.
3. Liquid atomization for fire control.
4. Production of aerosol "bombs" for the food, medical, hardware and toiletry industries.
5. Liquid atomization of chemicals for insect, disease, and weed control.

This was a study of liquid atomization as related to effective application of agricultural chemicals. However, techniques and results reported in this study may have application in other areas.

One important problem of the agricultural industry is the effective application of chemical sprays. The hazards associated with the use of many agricultural chemicals today makes the solution to this problem imperative.

Many investigators have experimented with agricultural chemicals and application equipment to determine formulations and application rates to accomplish particular jobs. Only a few of these investigators made any effort to quantitatively assess the atomized nature of the spray which carried the chemical. The production and drift of the smaller spray drops (and chemicals) was thought to be impossible to prevent and recommendations were to use "low volatility" chemicals, to form "large" drops, and to apply the spray only when the wind was nearly calm.

One of the major obstacles to effective chemical application has been the atomizing nozzle which characteristically produces a rather wide and unpredictable range of drop sizes. Little was known about the most effective drop size or sizes for particular applications. Also the technology to produce and transport desired drop sizes to areas of application without appreciable changes in character had not been developed.

It was the purpose of this study to explore a method of atomization different from those now in common usage in an attempt to develop an atomizing system that will produce spray composed of homogeneous particles of a predictable size.

CHAPTER II

OBJECTIVES

The objectives of this study were to:

1. Develop a technique to quantitatively measure the size distribution of particles formed from liquid atomization.
2. Determine and characterize the particle size distributions of sprays formed by different methods of atomization.
3. Refine a method of atomization that would produce spray containing a narrow size range of particles of a predictable size.

CHAPTER III

A REVIEW OF SPRAY TECHNOLOGY

The Atomization and Application of Agricultural Chemicals

Although the application of agricultural chemicals to crops in an atomized form was a relatively common practice prior to 1940, little attention was given to the mechanics of atomization as related to effective chemical application. French (1) made measurements of drop sizes in some test work with a compressed air sprayer and a blower sprayer. Using pressure atomizing nozzles with oil as the chemical carrier material, an increase in air velocity past the nozzle decreased the average drop size. The spray was collected on slides coated with lampblack and individual drops were measured with the aid of a microscope.

Following the introduction of 2,4-D shortly after World War II, several investigators (2, 3, 4, 5) became concerned with the spray distribution patterns of nozzles and the effects of pressure and nozzle arrangement on the uniformity of coverage. Shanks (6) discussed some methods of determining drop sizes, measured the drop size distribution of several nozzles and concluded that "present spray nozzles do not produce drops of great uniformity".

Many field experiments have been conducted involving the evaluation of chemical formulations and application rates where no measurements were made relative to drop sizes or distributions. A few investigators (7, 8, 9, 10, 11, 12, 13) have made rather cursory measurements of drop sizes and distributions as a part of field trials involving chemical evaluation. Most of these involved relatively crude sampling techniques and results were based either on qualitative visual assessment of the spray patterns or on the microscopic measurement of relatively few drops.

Roth and Reins (14) investigated a rotating disk apparatus in an attempt to produce a spray composed of drops of a uniform size. A laboratory device for producing drops of uniform size from small volumes of liquid was developed by Ennis and Ames (15). Others (16, 17) have used a paint sprayer to produce uniform drops for laboratory studies on the retention and effectiveness of chemicals.

Courshee (18, 19) investigated the small drop component of sprays and the occurrence of drift. He concluded that there is not a clear-cut upper limit to the size of drop that may drift since other factors (nozzle orientation, wind velocity, direction of travel) may be as important as the drop size itself in determining which particles will drift. Edwards and Ripper (20) describe a sprayer boom cover which would drape around the spray boom and catch and condense on the inside of the cover small drops that would otherwise drift. The results of field trials showed it to be reasonably effective in reducing the amount of spray that drifted.

Ennis (17) used sized drops to measure drop retention on different plant leaf types (pubescent and glabrous) for different types of liquid solutions. He found that pubescent leaves retained more aqueous spray than glabrous leaves and leaves in a horizontal position retained more spray than those at a 45 degree angle from horizontal. Smith (16) reported that sprays of relatively large drop size (250-561 micron average diameter) were more effective than those of smaller drop size (30 microns average diameter) as measured by plant response. For a given volume application rate, more spray solution was deposited and retained when the larger drops were used. Mullison (21) found in laboratory experiments that the herbicidal effect on young bean plants was determined solely by the amount of 2,4-D applied. Whether one large drop or several small drops were applied seemed unimportant as long as the total amount of 2,4-D used per plant was the same. Drop size, drop spacing, spray volume, and herbicidal concentration were studied by Behrens (22) to establish their relative importance in determining the effectiveness of 2,4,5-T spray application. Based upon the response of mesquite and cotton, the drop spacing (number of drops per square inch) was found to be of major importance in determining the effectiveness of the chemical while drop size, spray volume, and herbicidal concentration had no direct influence on plant response under the conditions of the test.

Drop Production Methods

Liquid atomization is the process of subdividing a liquid into a multitude of individual particles or drops. A number of methods have been proposed and developed to varying degrees which accomplish liquid atomization. The devices and techniques range from laboratory apparatus which will produce single drops or streams of drops to commercial equipment commonly used in a number of industrial processes.

Because of the vast quantities of literature available involving research on particular atomization devices, several excellent bibliographies are suggested (25, 26, 27, 28). The majority of research described in these references deals with pressure atomization and spinning disk atomization of fuels and of products for spray drying. The objective of atomization for these applications is to produce a uniform spray composed of fine drops.

Pressure Atomization. Pressure atomization consists of forcing liquid through an orifice. Liquid emerges from an orifice as a free liquid configuration in the form of a cylindrical column or a thin sheet. Because of surface tension, these configurations are unstable, and with the assistance of disturbances, subsequently break up into a system of drops.

Pressure (velocity) small enough to produce laminar flow causes liquid to emerge from a circular orifice as a cylindrical column or filament. At some distance from the orifice, external disturbances and surface tension forces cause the filament to undergo a breakup that produces rather uniform large drops about twice the orifice diameter and a few small drops irregularily interspersed between the large drops. This laminar flow breakup is sometimes referred to as the Rayleigh type breakup (26). Pressure on an orifice sufficient to cause semi-turbulent or turbulent flow causes the emerging liquid column to disintegrate into a range of drop sizes.

Liquid emerging from either a conventional fan or cone nozzle is first forced into a thin sheet. Internal and external disturbances resulting from liquid and ambient air turbulence may cause ruptures in the sheet. These holes enlarge rapidly into a network of liquid filaments which break up into drops. As liquid velocity (pressure) increases, the sheet and filaments become shorter, liquid and ambient air turbulence becomes greater and the entire atomization process becomes very difficult to detect and describe. Because of the unpredictable nature of the turbulence on the breakup of the sheet and filaments, the resulting drops necessarily cover a broad size range.

The manner in which the liquid emerges from the orifice greatly influences the atomization. Imparting a tangential velocity component to the liquid before discharge aids substantially in atomization. High pressures (velocities) increase the proportion of small drops. Viscosity has been found to be the principal liquid property influencing the degree of atomization. High liquid viscosity tends to increase the mean drop size in a spray.

Pneumatic Atomization. Liquid atomization in which a compressible fluid is used to disintegrate a liquid jet is known as pneumatic atomization. In the production of drops by this method, the breakup mechanism is characterized by a violent and unpredictable disruption

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and tearing apart of the liquid (26). The spray resulting from this process contains relatively large and unpredictable fractions of small drops. Depending on the liquid flow rate and relative air velocity, any large drops formed initially may subsequently be broken up into a number of much smaller drops.

Spinning Disk Atomization. Spinning disk atomization consists of centrifugally accelerating a liquid to a high velocity and discharging it into a gaseous atmosphere. The breakup mechanism at or near the periphery of the disk may be as direct drop formation, ligament formation or sheet formation. Experiments (23) have shown that disk configuration has a negligible influence on drop size distribution. The size and uniformity of drops produced depend to a large degree on disk speed, liquid feed rate, physical properties of the liquid (surface tension, viscosity, density), smoothness of the disk surface and the amount of disk vibration. The circulation and turbulence in the gas surrounding the atomizer also contribute to the unpredictable formation and breakup of the filaments and sheets. Drop size distribution characteristics of spinning disk atomization, with the exception of small diameter, high speed disks operating with low feed rates, closely resemble those of pressure atomization.

Jet Impingement. The impingement of two liquid streams or the impingement of a liquid stream against a solid surface will cause atomization.

Liquid-liquid impingement produces a ruffled sheet of liquid perpendicular to the plane of the two jets. The liquid sheet disintegrates intermittently, forming a group of drops that appear as waves propagating from the point of impingement. Heidmann and Humphrey (29) studied the effect of jet velocity, jet character, jet length, and impingement angle on the wave frequency of two impinging jet streams. No measurement was made of the drop size-distributions produced.

The breakup mechanism of liquid-solid atomization has not been described. However, at least one commercial nozzle uses this principle in producing a "fog" for fire fighting. This principle is also in common use in equipment for the application of garden insecticides where a liquid stream impinges on a plane or curved surface to cause atomization. Quantitative assessment of drop size distributions for these atomizers is not available.

Aerosol Generation. Aerosol generation (30) is a process of condensing vapors on nuclei to form drops of a desired size. (Aerosol is a term generally used to designate an assemblage of small liquid or solid particles 50 microns in diameter or less that are dispersed in a gaseous medium). By careful control of this process, clouds of extremely uniform drops can be formed.

Atomization by the Use of Electrical Energy. Vonnegut and Neubauer (31) and Drozin (32) have demonstrated with laboratory apparatus that certain liquids can be atomized using high voltage electricity. When a wire carrying 5,000 to 10,000 volts was immersed in an insulated liquid-filled vessel having a capillary discharge tube, streams or clouds of uniform drops were produced. The size of the drops and degree of atomization was largely a function of the applied voltage. The drops produced were highly charged and could be controlled by electrostatic means. Drozin found that it was not possible to atomize some liquids even at voltages up to 30,000 volts.

High voltage has been used for atomization in a painting process (33). As paint flowed from the edge of a rotating head, a 90,000 volt potential created between the head and the work assisted in the atomization and transportation of the paint to the work.

Liquid Atomization by Vibrations. The application of vibratory energy to atomize liquids has resulted in several laboratory devices and techniques which can produce streams or clouds of drops.

Rayner and Hurtig (34) and Davis (35) developed devices by which a vibrating wire, moving through the liquid that accumulates at the end of a capillary tube, would strip small drops from this mass of liquid. Drop size was found to depend mainly on the liquid flow rate from the capillary tube and to a lesser extent on the frequency and amplitude of the wires. Wolff (36) used an electromechanical vibrating reed device and an analogous mechanical device to study inconsistent drop size, the presence of satellite drops and the mechanism of drop formation by this method of drop production.

Dimmock (37) was able to generate a stream of drops of uniform size by vibrating a capillary tube containing liquid. By adjusting the liquid feed rate and frequency of vibration, drops ranging in size from 10 to 300 microns were produced. Vonnegut and Neubauer (38) describe a similar technique that utilized a blast of air to excite the capillary vibration.

Magarvey and Taylor (39) developed two types of devices for producing large drops. In one a jet stream was broken up into drops of uniform size by a forced vibration of the discharge tube. In the other, vibrations were transmitted to the jet stream through the liquid contained in the discharge chamber. These devices produced drops ranging in size from 300 to 10,000 microns.

Sliepcevich, Consiglio and Kurata (40) describe a pressure type nozzle which used a discharge valve that was made to vibrate at from 200 to 800 cycles per second. For a given capacity, finer spray was obtained from this nozzle than from a conventional non-vibrating centrifugal pressure nozzle. A device using sonic vibrations (41) was used to atomize liquid. Filaments of liquid showering down around a resonator, vibrating at about 9400 cps, were broken up by waves of pressure and dilation.

Antonovich (42) made high-speed motion pictures of a paint film atomized by 20 kilocycle vibrations. Under the best atomizing conditions at 20 kilocycles, the drop diameters ranged from 20 to 70 microns. Sollner (43) described the mechanism of "fog" production of non-metallic liquids by the use of ultra-sonic waves. No mention was made of the size of drops produced. Three patents (44, 45) have been issued on atomizing devices utilizing ultra-sonic energy as a means of achieving atomization.

<u>Miscellaneous Atomizing Devices</u>. The following atomizing devices and techniques do not exactly fit any of the classifications previously

established.

A rotary device for producing a stream of uniform drops in the laboratory was developed by Rayner and Haliburton (46). In this device the tip of a rotating blade moved through a reservoir of liquid and upon emerging from the liquid surface caused drops to be thrown off. Drop sizes ranged from 100 to 700 microns depending upon blade speed, blade tip design, and size of liquid feed capillary.

Lane (47) developed a device for producing single drops of a predictable size that consisted essentially of a hypodermic needle discharge tube with a concentric air stream to strip off the drops. A similar device was developed by Ennis and James (15) to produce uniform drops from small volumes of liquid.

A rotating cylinder was developed by Britton and Norman (48) for atomizing chemicals for aerial application. This device consisted of a perforated cylinder 4 inches in diameter and 14 inches long into which liquid was fed. At rotative speeds from 10,000 to 15,000 revolutions per minute, atomization was maintained at liquid feed rates of "several" gallons per minute. Drop size was observed to be a function of rotative speed.

Although mechanical division of liquids is a possible means of atomization, no reference was found to a device or process that utilized this principle.

Spray Sampling Methods

Numerous sampling methods have been developed in the measurement of spray drop size. No one method has proved entirely satisfactory. DeCorso (49) suggests the necessary characteristics for an ideal drop sampling method:

1. The spray pattern for atomization should not be disturbed in the sampling process.
2. Sampling should be rapid.
3. The samples should readily lend themselves to rapid counting.
4. The samples should provide good size distinction over the entire range of drop sizes to be measured.
5. The method should permit the variation of liquid and ambient gas properties.
6. The samples should be taken in such a manner that spatial and temporal size distributions can be obtained.

The known sampling methods are described in the following paragraphs for comparison with the characteristics of an ideal method. Details of particular methods may be found in the indicated references.

<u>Coated Slide Method (6, 14, 22, 27, 50)</u>. A frequently used method is the collection of drops on slides coated with a suitable material. This method provides a rapid and simple means of sampling since it is easily adaptable to a wide range of sampling conditions in either laboratory or field experiments. Several important difficulties occur in the use of this method, however. Some difficulty may occur in obtaining reliable samples since small drops may flow around the slides and large drops may be shattered upon impact with the slides.

Careful control must be maintained over the sampling interval to avoid an over-concentration of drops which would hinder subsequent measurement. The resulting drop impression on the slide must be carefully calibrated with the actual drop size to obtain accurate size information. This method of sampling generally provides records that do not deteriorate appreciably with time.

Immersion Sampling (51). In this method drops are collected in transparent sampling cells containing a liquid of lower density than the spray and one that is immiscible with the spray. After entering a cell, spray drops settle to the bottom and remain as practically perfect spheres. As with the coated slide method, sampling error may occur because of the failure of small drops to impact and because of the shattering of large drops at impact. Care must be exercised to keep the concentration of drops low enough to prevent appreciable coalescence in the cell. The cells must be handled gently to prevent coalescence before measurement.

Frozen or Solidified Drop Method (27, 50). This method involves the freezing or solidifying of spray drops in flight. The solidified drops can then be collected, sieved, and separated into size classes for counting. Although the materials used to simulate the spray liquid may have approximately the same physical properties (viscosity and surface tension), the effect of the freezing process on drop size is not well known. It is possible with this method to sample a large volume of a spray and thus reduce one type of sampling error.

Photographic Method of Sampling (27, 49, 50, 52). This method consists of photographing spray drops in flight. The general arrangement is to pass spray between the camera and a light source. Due to the velocity of the drops and the magnification generally sought in the photographic process, special illumination techniques are required. Also, at high magnification the depth of field becomes very small and difficulty arises in determining which drops are sufficiently in focus for counting. By the use of high speed flash equipment and double exposures of the film, both spatial and temporal distributions can be obtained. Since no object is placed in the path of the drops, there is minimum disturbance of the spray during the sampling process.

The Cascade Impactor Method (27, 50). In this method spray drops are made to flow through a passageway and are impacted on slides placed in the path of the drops. Drop size gradation occurs at different points in the system due to a difference in air velocity at each sampling point. This method is not especially suitable for determining the drop size distribution in coarse sprays because of impingement of large drops on the walls of the impactor. Sprays containing drops under 100 microns in diameter can be sampled accurately in this manner.

Electronic Sampling (27, 50). Several electronic techniques have been developed for sampling and measurement of spray drop sizes. Geist, York and Brown (53) found that the electrical pulses created upon interception of electrically conducting particles with a probe wire were proportional to the particle diameter. Clardy and Talbert (54) developed an instrument using a phototube scanner to continuously measure and record raindrop size distributions. An electrically heated filament was used by Vonnegut and Neubauer (38) to detect and measure airborne liquid drops. Considerable development of these techniques and associated equipment is necessary, however, before accurate and reliable information can be obtained.

Light Scattering (27, 50). The measurement of light scattered from dispersed drops is a rapid method of obtaining size information. However, only information about the average drop size or the predominant size is available with this method. The accuracy of this method depends largely on the uniformity of dispersion of the drops.

Other Methods (27, 50). Several other methods have been developed for the sampling of solid and liquid particles. Elutriation, centrifugal separation, and radioautographic methods have been developed for solid particles. No applications of these methods have been made to the sampling of liquid particles. Momentum and mass flow measurement techniques developed for sampling liquid particles yield only rather gross characteristics of the spray.

An important part of a spray sampling method involves decisions concerning the number and location of samples to obtain representative and reliable data. Only vague and incomplete discussions of this aspect of sampling are found in the literature. Generally, in sampling sprays for drop size distributions, more emphasis seemed to be given to the total number of drops counted than to where or how the drop samples were obtained.

Tate and Marshall (57) suggest that the accuracy of characterizing an actual drop size distribution depends on the number of size ranges used and on the total number of drops to be reported. To establish a desired total number of drops to be measured an "error factor" was developed that represented the deviation from an actual cumulative distribution curve of a measured cumulative distribution curve as a per cent of the total number of drops measured. Judicious selection of sampling locations with respect to the areas of greatest spray volume was also deemed necessary to avoid increasing the total number of drops to be measured as predicted by the error factor function. In experiments with centrifugal pressure nozzles, twelve immersion samples (two per location) were taken along a line perpendicular to the nozzle axis at positions representing midpoints of annular equal volume zones. Photomicrographs were made from the samples for counting, though no indication of the number made from each sample. The drop size distribution sampling distance was the same as for the weight flow distribution sampling. Adler and Marshall (23) and Herring and Marshall (63) used a similar sampling procedure for spinning disks but indicated that from 10 to 15 photomicrographs were made from each one inch square sampling cell. No indication was made of sampling replication of the cells. In discussing the technique of immersion sampling, Tate (51) suggests a sampling distance far enough from the orifice to allow large drops time to slow down and thus prevent drop shatter on impact with the immersion cell fluid. One test was suggested as sufficient to establish drop size distributions by using a long narrow cell extending across a symmetrical spray pattern. The contents of the entire cell were not examined.

Rather, photomicrographs were taken at spaced intervals along the cell for measuring and counting.

DeCorso (49) raised the question of how many drops should be counted for his photographic sampling method. Each negative in his experiments was treated as an individual sample, but no indication was made of the number of replications or sampling locations used. A sampling distance was specified, but no mention was made as to why the selected distance might have been better or worse than any other.

Pigford and Pyle (64) exposed two or three coated slides to each spray under duplicate conditions. No indication was made as to where in the spray pattern the samples were taken. The coated slides were then photographed at a magnification of ten and the drops counted in three or four narrow strips across the negative.

Turner and Moulton (58), working with the molten wax method, placed one per cent (by weight) of the total particles collected in a liquid suspension from which several drops were drawn and placed on a slide. Upwards of 90 fields of drops were counted from each slide. One to three slides were prepared for each test condition.

Drop Measurement Techniques

Several techniques have been developed to assess samples of spray for the number and size of drops. The method used for measurement will depend to a large extent on the number of samples to be counted and on the method by which the samples were obtained.

Manual counting and sizing of spray samples, either directly with the aid of a microscope or similar magnifying device equipped with suitable measuring attachments or indirectly by being photographed and projected (the measurements being made from the projected images), is perhaps the most common method employed. Although this method is a tedious and time-consuming procedure and imposes a limit to the number of samples that can be analyzed, it does provide a means of counting samples regardless of the method used in taking the samples. Some electro-mechanical measuring and recording devices are available to help speed the manual assessment of samples.

An electronic scanning device and technique has been developed (55, 56) which can be used to count and classify chordal images from high contrast photographic negatives of spray drops. The chord distribution data assembled by the instrument will yield drop size distributions after proper statistical treatment. The immersion sampling method lends itself especially well to this technique of analysis since high contrast negatives are usually obtained. The uncertain depth of field associated with the photographic method of sampling would likely prevent these negatives from being analyzed directly by this method. Certain slide coatings will produce photographic negatives of sufficient contrast to use with this method. The principle advantages of this method are that it counts and classifies all of the drops on a photographic negative and can count much faster with greater accuracy than a human.

Samples obtained by the frozen drop method can be quickly separated into several size classes by passing them through a set of standard sieves. The major limitation to this procedure is that the number of sieve sizes available restricts the number of size classes that can be obtained. Also, particles smaller than about 50 microns cannot be separated by sieves and must be subjected to other methods for analysis. The number of particles in each size class can be determined by either counting the entire sample or by a process of weighing and counting representative sub-samples.

The other sampling methods (light scattering and electronic sampling) produce indirect drop size measurements and would need careful calibration in their use.

Portrayal of Drop Size Distributions

The drop sizes found in sprays are commonly portrayed in a number of different manners, some of which provides more information than others. The procedure has generally been to calculate diameters of "typical" particles from experimental data or to fit distribution functions to experimental data.

Depending upon the atomization application, any one of several mean diameters may be found: length or diameter, area or surface, volume, surface-diameter, volume-diameter, volume-surface, and geometric. Also, calculated median diameters are used to divide the spray into two equal portions by number, surface area or volume bases and can be established from the 50 per cent point on a "per cent smaller than a given drop size vs. given drop size" cumulative distribution curve. Median diameters and mean diameters, by themselves, relate very little information about the distribution of drops within a spray.

Several functions have been developed and are used to represent drop size distributions in sprays and may be expressed as number, surface or volume distributions:

1. Normal distribution function

$$f(x) = \frac{1}{s\sqrt{2\pi}} e^{-\frac{(x-\bar{x})^2}{2s^2}}$$

$\bar{x}$ = mean drop size

s = standard deviation

2. Log-normal distribution function

$$f(x) = \frac{1}{x s_g \sqrt{2\pi}} e^{-\frac{(\ln x - \ln \bar{x}_g)^2}{2 s_g^2}}$$

$\bar{x}_g$ = geometric mean diameter

s_g = geometric standard deviation

3. Square root - normal distribution function

$$f(x) = \frac{1}{2\sqrt{2\pi s x}} e^{-\frac{(\sqrt{x} - \sqrt{\bar{x}})^2}{2s^2}}$$

$\bar{x}$ = mean drop size

s = standard deviation

4. Upper limit function (log-normal function with parameter for upper limit to drop size)

$$f(x) = \frac{1}{s_g \; x \sqrt{2\pi}} \; e^{-\frac{\ln\left(\frac{x_m - x}{\bar{x}_g}\right)^2}{2\, s_g^2}}$$

x_m = maximum drop size

$\bar{x}_g$ = geometric mean diameter

s_g = geometric standard deviation

5. Modified log-normal function

$$f(x) = \frac{K}{x s_g \sqrt{2\pi}} \; e^{-\frac{(\ln x - \ln \bar{x}_g)^2}{2\, s_g^2}}$$

$\bar{x}_g$ = geometric mean diameter

s_g = geometric standard deviation

K = adjustment factor

6. Nukiyama - Tanasawa distribution function

$$f(x) = b x^m \; e^{-c x^d}$$

b, m, c, d are empirical constants

7. Rosin - Rammler distribution function (in cumulative volume form)

$$V_f = 1 - e^{-\left(\frac{x}{x_p}\right)^d}$$

V_f = volume fraction contained drops of diameters less than x

x_p = size parameter

d = dispersion parameter

Four of these functions are empirical variations on the normal distribution curve. The log-normal function provided certain advantages (24) when representing selected spray data. Tate and Marshall (57) used the square root-normal function for spray from centrifugal pressure nozzles. The upper limit function, which acknowledged the maximum drop size in sprays was developed by Mugele and Evans (24). Turner and Moulton (58) devised an adjustment factor for the log-normal function to better represent their data. The Nukiyama-Tanasawa function is a strictly empirical equation having application over a limited range (24). The Rosin-Rammler function was originally developed for solid particle distributions (powdered coal) but has found occasional application in liquid atomization.

All of these functions are used to characterize, in a rather gross manner, the spatial drop size distribution of an entire spray pattern, i.e., the size distribution of drops in a volume of spray. A number of samples may be taken at different locations in a spray but are subsequently combined to provide a composite distribution for the atomizer. Little or no attempt is made with these functions to identify distributions in different locations within a spray pattern. Also, the temporal distribution, that is, the distribution of the drops and/or liquid mass as a function of time is not shown by these functions.

York and Stubbs (52) developed a function for cone nozzles where the "number of drops per centimeter per steradian per cubic centimeter of flow was plotted against the size of drops for various locations in a spray". This function represents a more precise description of an entire spray pattern and would facilitate comparisons between nozzles since the spray flux is expressed in terms of a unit solid angle rather than unit cross-sectional area and would take into account dispersion of the spray as distance from the nozzle changes.

No one of these distribution functions has proven to be best, and as Marshall suggests (26):

> "Until atomization mechanism can be suitably related to one or more distribution functions, there seems to be no theoretical justification for a belief, or expectation, that one function should be generally superior to another for representing droplet-size distribution. Probably the best reasons for selecting a given distribution function would be (1) mathematical simplicity, (2) ease of manipulation in computation, and (3) consistency with the physical phenomena involved."

Electrostatic Dispersion

In reviewing drop production methods, it appeared that electrostatic atomization offered promise as a non-mechanical means of subdividing a liquid into a homogeneous spray composed of particles with sufficient charge that electrostatic forces would determine drop movement.

The electrical atomization achieved by Vonnegut and Neubauer (31) and Drozin (32) resulted in charged drops of 100 microns or less in diameter. Under certain atomizing conditions (particularly with liquids of very low conductivity) clouds of very small (about one micron diameter) charged particles of great uniformity were produced. The drops would be charged to the polarity of the high voltage electrode immersed in the liquid. The capillary discharge tubes used were on the order of 100-500 microns in diameter with only sufficient liquid pressure on the discharge tube to cause a few drops a minute (about 5×10^{-6} cm^3/sec) to be formed at zero liquid potential. When a voltage was applied, the drop production rate would increase though no measure was made of any change in flow rate.

Magarvey and Outhouse (59) investigated the breakup of a charged jet stream emerging from a 300 micron orifice at a flow rate of 0.5 cm^3/sec. Measured currents in excess of 10 micro-amperes caused a violent whipping of the stream and subsequent disintegration into a wide range of particle sizes. Many drops ranging in size from less than 5 microns to about 25 microns were observed to leave the atomization point at relatively high velocities such that about 60 per cent were within 30 degrees of horizontal (for a vertical jet stream). The larger drops continued in the direction of the jet stream unless caused to deviate by forces created during breakup or by electrostatic repulsion of nearby particles. The persistence of the electrical charges on the drops was not noted.

In studying the effects of electric fields on rain drop coalescence, Goyer, et. al. (60) found that surface charges could be induced on drops by passing them between charged plates. The induced charges on the drops were of sufficient magnitude that dispersion of the drops was observed due to mutual repulsion of the similarly charged drops.

CHAPTER IV

THE DESIGN AND DEVELOPMENT OF A SPRAY SAMPLING APPARATUS AND TECHNIQUE

Selection of a Method

A review of research involving the application of agricultural chemicals showed that a deficiency existed in not being able to accurately sample, measure, and define the particulate nature of sprays. Since the validity of all subsequent analysis depends on the integrity of the original samples, it was decided that the sampling technique for this study should be developed around the collection of accurate and representative samples of spray drops. Thus, two requirements were established for a spray sampling method: (a) samples should be taken in or very near the zone of atomization to prevent environmental modification of the drops and (b) the sampling method should produce minimum disturbance to the atomization process.

The photographic method appeared to best satisfy these requirements and provided other desirable features. Since no object is placed in the path of spray drops, a minimum of disturbance is created in the sampling process. Drop coalescence, dispersion, and evaporation do not distort measurements of the atomizing process. Drop size distinction can be maintained over a wide range of drop sizes. With proper equipment, both spatial and temporal distributions can be obtained. The sampling procedure is relatively rapid and results in permanent records.

General Arrangement of Components

The sampling apparatus consists essentially of a high magnification camera, a light source, and a spray chamber mounted on a rigid frame (Fig. 1, 2). The camera and light source were arranged on opposite sides of a spray chamber. This arrangement resulted in a type of shadow photography where the spray drops would appear as white spots in a dark field on developed film. Difficulties in properly illuminating spray by reflecting light from the drops was reason for rejecting an arrangement having the camera and light on the same side of the spray chamber.

The spray chamber was designed to provide a zone through which spray could move, affected only by self-generated air currents. The movable chamber walls could be made to enclose the sampling zone and the atomizing device. Different sampling locations could be obtained by moving the atomizing device vertically or horizontally with respect to the camera.

Camera Design

York and Stubbs (52), DeCorso (49), and Pelej (61) used a camera magnification factor of about 10. No reasons were given as to why this particular magnification was used. If care is exercised in the

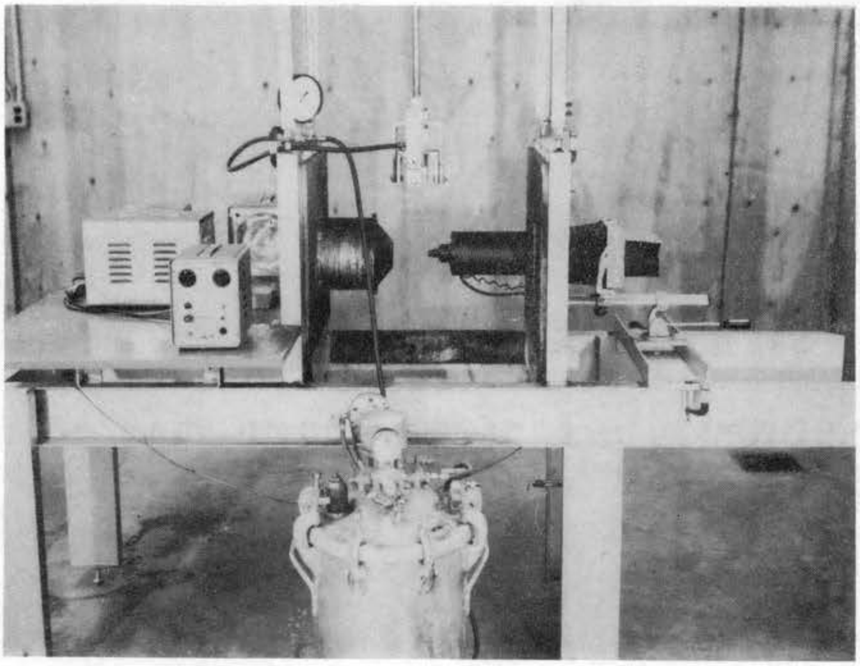


Fig. 1. The Photographic Spray Sampling Apparatus.

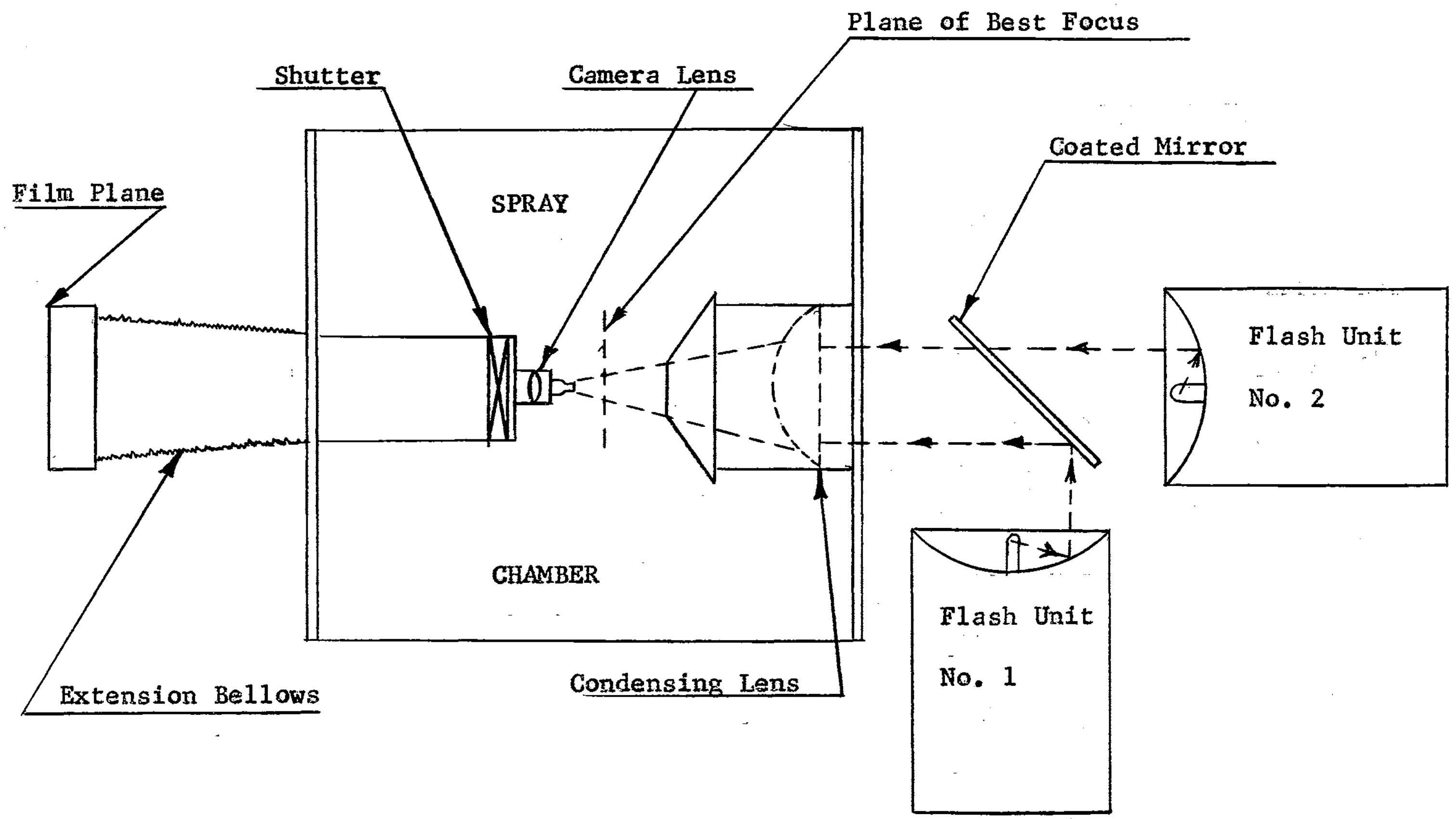


Fig. 2. Schematic Diagram of Spray Sampling Apparatus.

selection and use of a camera lens, less distortion is likely in the photographic process than in enlargement or projection of the negatives for measurement. Thus, from the standpoint of drop image distortion, a large photographic magnification factor is highly desirable. On the other hand, a large magnification factor results in a small sampling area. Also, as the magnification factor increases, the image distance (the distance from the lens to the film) increases and the amount of light required to properly expose the film increases. The magnification factor partially determines the smallest size of particle that can be photographed and measured accurately.

For the purpose of this study a maximum magnification factor of about 20 was arbitrarily selected. Since measurements might be directly made from a photographic negative, this magnification would be necessary to measure drops 50 microns in diameter. Drops 50 microns in diameter would appear approximately 0.04 inches in diameter on a negative with a magnification factor of 20. The minimum drop size that can be photographed with this magnification is determined by the resolving power of the camera lens and/or the film used.

To obtain a magnification factor of 20 while maintaining a reasonable image distance, a short object distance (the distance from the lens to the object) must be used. An object distance of about 2 inches was selected to satisfy this requirement. This distance was considered sufficient for the creation of an adequate undisturbed sampling zone in front of the camera lens and at the same time would result in an image distance of about 40 inches. The focal length of the lens required to provide these distances was calculated as 1.91 inches using the optics equation 4-1 relating focal length, image distance, and object distance:

$$\frac{1}{F} = \frac{1}{I} + \frac{1}{O} \qquad 4 - 1$$

F = focal length

I = image distance

O = object distance

It is apparent from equation 4-1 that where the object is located very close to the focal length of the lens, small changes in the object distance produce rather large changes in the image distance and the magnification factor. For a compound lens the object distance and image distance should be measured from the front and rear nodal points. With normal photographic lenses, however, the nodal points are not unduly separated and only a small loss in accuracy will result if the distances are measured to the center of the lens.

A 50 mm. (1.97 inch) focal length f/3.5 Leica Elmar camera lens was selected. This lens provided acceptable mechanical and optical properties as well as a desirable focal length. The object and image distances for this lens with a magnification factor of 20 were calculated using equations 4-2 and 4-3 to be 2.07 and 41.4 inches, respectively.

$$O = F\left(1 + \frac{1}{m}\right) \qquad 4 - 2$$

$$I = F\left(1 + m\right) \qquad 4 - 3$$

m = magnification factor $\frac{I}{O}$

At this magnification the depth of field was calculated to be 0.020 inches (see Appendix A-I). This calculation was made with the lens iris adjusted to f/8. Larger f numbers (smaller effective aperatures) would provide a greater depth of field.

The lens was mounted in a cylindrical barrel attached to one wall of the sampling chamber and projected into the chamber. Much of the superstructure of the lens was removed to decrease the outside diameter of the barrel and reduce interference with the spray near the sampling zone. A lens filter ring was adapted to support an extension tube of reduced diameter which would help prevent the spray from impinging on the lens during sampling. An extension tube cover prevented spray drops from accumulating on the lens when samples were not being taken.

To provide for a desired magnification a special extension bellows was used. One end of this bellows was mounted to the outside of the sampling chamber wall and the other to the front side of the rear frame of a Graflex view camera. The view camera was mounted on a track to provide magnification adjustment not permitted by the camera itself. The rear frame of the camera was fitted with a 4 x 5 Graflok back which could be positioned from about 16 to 48 inches from the center of the lens. A grid of number 36 wire was installed at the back of the camera directly in front of the film holder. This wire grid produced a fine-lined silhouette on the film to assist in negative assessment.

A number two Alphax MX self-cocking shutter was mounted directly behind the lens in the barrel. A manual shutter release cable and shutter electric cord extended from the barrel and the chamber to control the shutter. The iris of the shutter was adjusted to a wide open position (1 inch diameter) and offered no restriction to light passing through the camera lens. Adjustment of the shutter speed could be made from the end of the barrel without removing the lens.

Illumination

In order to obtain clear, sharp photographs of moving objects, it is necessary that image movement across the film be very small. Chesterman (62) suggests that "the image movement across the film during effective exposure should not exceed about 0.001 inch". The exposure time (image movement) can be controlled either by regulating the camera shutter speed while the object is illuminated or by regulating the duration of illumination during the period the shutter is open.

Maximum drop velocities of about 1500 centimeters per second (50 feet per second) were measured by York and Stubbs (52). Limiting image movement across the film to 0.001 inch at this velocity would require a camera shutter speed of 1.7 microseconds or a flash with a 1.7 microsecond duration. Since shutter speeds in the microsecond region are difficult to achieve, a short duration flash unit was selected.

An Edgerton, Germeshausen, and Grier type 549 Microflash was selected as the light source. This unit delivered a single 50 million peak beam candle power flash of approximately 0.5 microsecond duration (flash duration is defined as the time that the light intensity exceeds the one-third peak value). The type 549 Microflash employed a high-voltage, guided spark-gap air flash tube producing a light spectrum having a large part of the light energy emitted in the blue-green region (4,000 - 6,000 Angstrom units). A reflector was employed to concentrate the flash into a beam.

To obtain sufficient light for properly exposing the film at maximum camera magnification, it was necessary to mount a light condensing lens between the flash unit and the camera lens. A seven-inch diameter condensing lens with a ten-inch focus was mounted in a barrel on the spray chamber wall opposite the camera and positioned so that a zone of intense illumination about one inch in diameter was created at the plane of best focus in front of the camera lens. To help maintain an efficient optical system, a truncated conical sheet metal cover was mounted on the end of the condenser lens barrel which reduced spray impingement on the lens.

Drop velocities were obtained by double exposure of the film from two successive light flashes of a known time interval. Average drop velocity was then obtained by dividing the drop image movement on the negative by the time interval between flashes. Because the time interval between flashes for double exposure was small compared with the minimum recycle time for the type 549 Microflash, two flash units were required. The light from these two units were combined into a single beam so that both exposures were identical. Two alternatives were examined for combining two light sources into a single beam.

One arrangement consisted of a one-fourth inch diameter flexible fiber optics "light pipe" fabricated in the form of a "Y" with fibers in each branch being distributed in the trunk. Light entering either branch from a flash unit appeared as coming from the same source. Condensing lenses were used between the flash units and the entrances to the light pipe. Despite this concentration of light, losses at the entrances to the light pipe branches were so great that the remaining light passing through the light pipe was insufficient to properly expose film. Further work with this arrangement was discontinued.

In the arrangement used, the two flash units were arranged at right angles, one of which pointed directly into the condensing lens in the spray chamber (Fig. 3). Light from the two units was combined into a single beam by a specially coated glass plate mounted at 45 degrees in front of both flash units. This coated glass transmitted light from each unit toward the light condensing lens in the spray chamber. The glass was coated with the Libbey-Owens-Ford #501 Hi-Efficiency coating that reflects half and transmits half of the light falling on its surface. A variable time delay in the flash units permitted one unit to be flashed a predetermined interval of time after the other.

Photographic Techniques

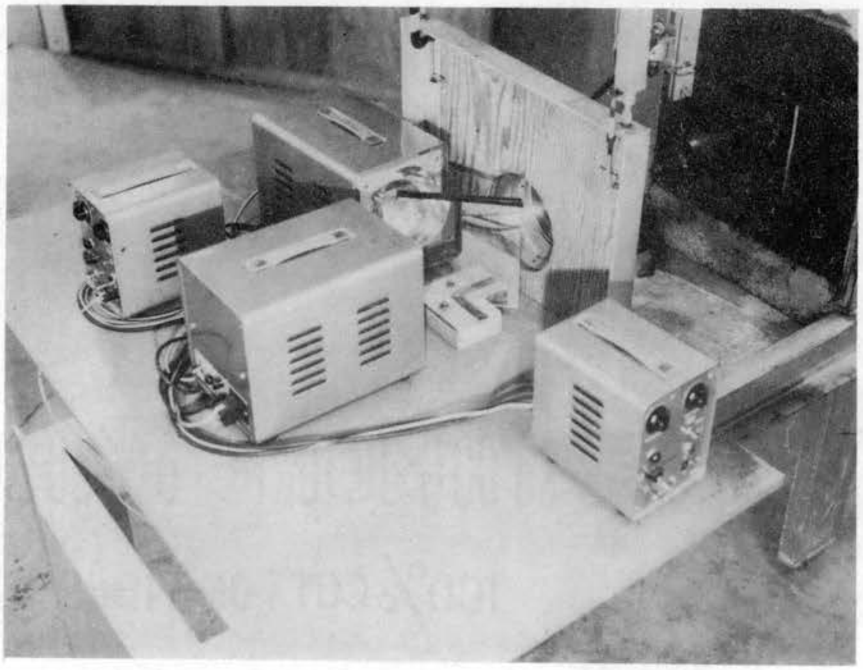


Fig. 3. Arrangement of Flash Units for Double Exposure Photography.

Because of the extremely small depth of field, great care was necessary in positioning the atomizer for specified sampling locations. A General Radio Type 1531-A Strobotac was used as the light source for focusing adjustment and for other observations where a multiple flash was desired.

Synchronization of the camera shutter opening and light flash was achieved by using the "X" contacts of the shutter (which made contact just when the shutter was fully open) to trigger one of the flash units. The other flash unit, triggered by the light flash from the first unit, had an adjustable delay period ranging from 0 to 1000 microseconds following the first flash. A flash delay calibration was made by photographing a rotating disk driven by a synchronous motor. Shutter speeds of one second or less permitted exposure of the film by the short duration flash without causing fogging of the film by extraneous light.

A fine grain, very high contrast film (Kodak Contrast Process Ortho) was used to provide sharp separation boundaries for the drop images on the film. The film was developed in D-11 developer for 14 minutes at 68 degrees Fahrenheit to obtain maximum contrast. Polaroid film (P/N 55) of about the same speed as the Contrast Process Ortho was used to great advantage to check the photographic setup before each test series.

A nigrosine dye was added to transparent liquids at about one per cent by weight to make the drops opaque and produce sharp drop image boundaries on the negatives. The effect of the nigrosine dye on the viscosity and surface tension of water is presented in Appendix A-II.

Drops were photographed in varying degrees of focus due to the small depth of field. Depth of field standards were prepared by photographing drop-like objects at different measured locations from the plane of best focus. These negatives provided guidance in deciding which drops were sufficiently in focus to be measured and counted.

Although the camera magnification capability was designed for a maximum of 20, the small depth of field and sample area associated with this magnification was not satisfactory for certain sampling conditions. Camera magnifications of from 8 to 12 were satisfactory for most work and provided a sample area of about 0.5 inch square. These smaller magnifications also made proper illumination less difficult and provided greater freedom in depth of field adjustments.

Individual sample (negative) identity was maintained by mounting a small number inside each film holder in front of the film to provide a permanent identification for each negative upon exposure. The same number was also taped to the outside of the holder. This numbering system permitted mass development of a group of negatives since each negative carried its own identification. The numbers on the outside of the film holders were recorded for the different test conditions as exposures were made. Following film development the numbered negatives could then be associated with the proper test condition.

Negative Assessment

Sample negatives were scanned on a Wilder Model A Optical Comparator having a magnification of ten. A magnification of ten was about the limit of enlargement for the film used and provided a desirable scanning area on the viewing screen. Since the negatives were divided into several one inch square areas by the fine grid wires, a ten times enlargement of one of these areas just filled the viewing screen. The comparator was equipped with a grid chart having a one millimeter line spacing. Thus, with a camera magnification of ten and a comparator magnification of ten, drop images of about ten microns in diameter were the smallest that could be measured.

In an attempt to speed negative assessment, an electro-mechanical drop-size recorder was assembled. This device recorded the number of drops occurring in as many as 15 different size classes of about 60 microns per size class (Fig. 4). After some use of this device, it was found that negatives could be scanned almost as fast by two persons one measuring and the other recording. Drop size and number data obtained without the use of the recorder were processed in digital computer programs with more flexibility since individual drop sizes were known and no previous size class limitations were imposed.

The depth of field standard negatives were reviewed periodically in an attempt to maintain consistency in sample assessment.

Flash Delay Calibration

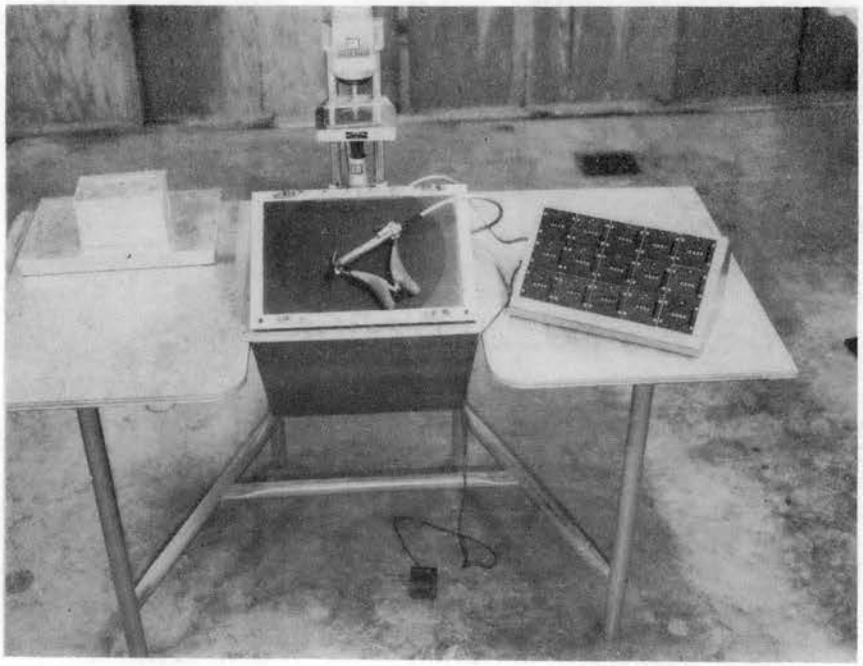


Fig. 4. Drop Size Recorder and Optical Comparator.

Since part of the work with the sampling apparatus would involve drop velocity measurements, it was necessary to obtain a flash delay calibration for the flash units.

To accomplish this, a protractor was carefully photographed to a four-inch outside diameter and the negative cemented to a cardboard disk. Diametral measurements between the tips of opposing graduations at the edge of the protractor were made from the negative. The disk was mounted on the shaft of an 1800 RPM fractional horsepower synchronous motor. With the motor rotating the disk at synchronous speed, double exposure pictures were taken for different delay settings of the flash units. Chordal measurements of the disk graduation movements were obtained from the negatives (Fig. 5) and were converted to seconds of flash delay using the following equation based on circle geometry:

$$T = \frac{60}{\pi N} \tan^{-1} \frac{X}{\sqrt{(B^2)(Y^2) - (X^2)}} \qquad 4 - 4$$

T = delay between flashes (seconds)

X = chordal graduation movement (inches)

Y = diametral distance between opposing graduations (inches)

B = camera magnification

N = disk speed (revolutions per minute)

Since the disk speed could be measured only to the nearest 5 RPM with the stroboscope, a calculation was made to determine this

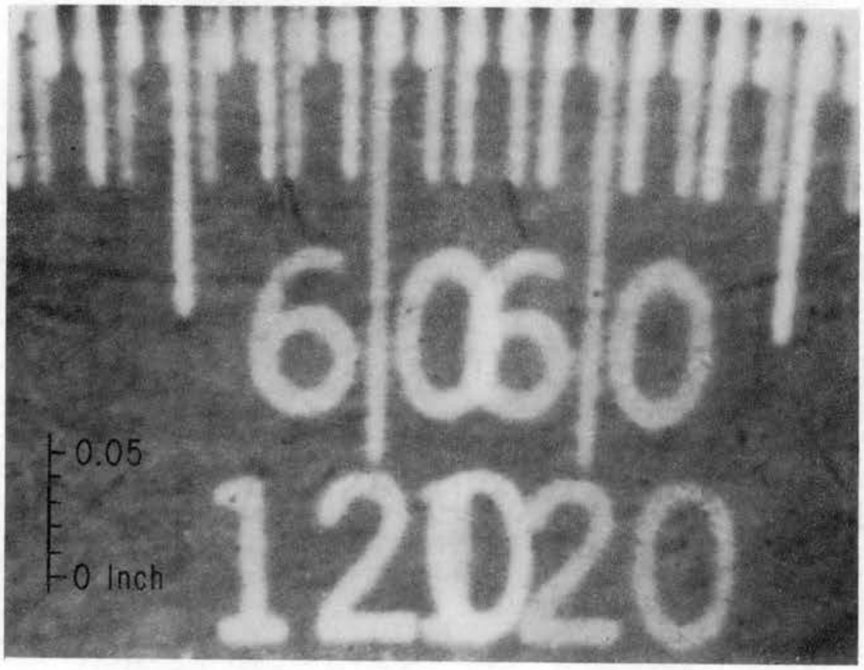


Fig. 5. Double Exposure Sample for Flash Delay Calibration.

effect on the delay calculated using equation 4-4. The result showed that a change of 5 RPM in the disk speed would produce a change of 0.1 microsecond for a 40 microsecond delay period and 3 microseconds for a 900 microsecond delay period, both of which were considered insignificant for the accuracy desired.

CHAPTER V

APPARATUS AND EQUIPMENT FOR EXPERIMENTS

Equipment for Sample Replication, Sample Distance and Sample Location Experiments

The equipment developed and added to the sampling apparatus consisted of a spray nozzle positioning device and a liquid pressure system.

The nozzle positioning device was supported by a rigid overhead frame (Fig. 6) extending 18 inches above the spray chamber. Two carriages supported by the frame allowed lateral and longitudinal movement of the nozzle with respect to the camera axis. The carriages were clamped to their tracks with "C" clamps when a desired position was established. A one-inch diameter shaft extended vertically through the longitudinal moving carriage providing a vertical adjustment. The nozzle holding and positioning device (Fig. 7) was located at the lower end of the vertical shaft. This device allowed angular movements of the nozzle body in two planes without displacement of the orifice when the orifice was positioned in the same horizontal plane as the centerlines of the bracket pivot bolts. Samples (photographs) could then be taken at a constant distance from the orifice anywhere in the spray pattern by rotating the nozzle body through

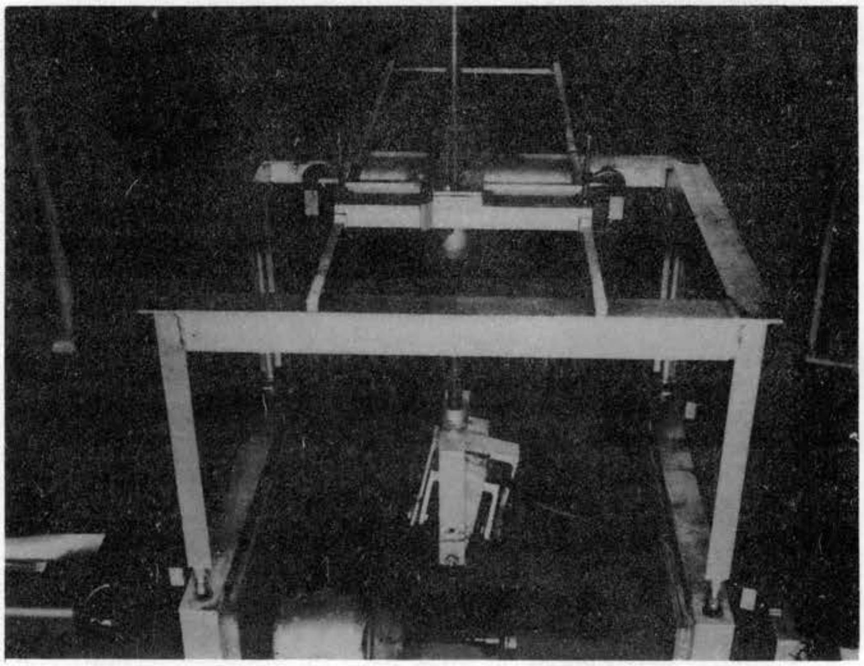


Fig. 6. Overhead Frame for Nozzle Holder.

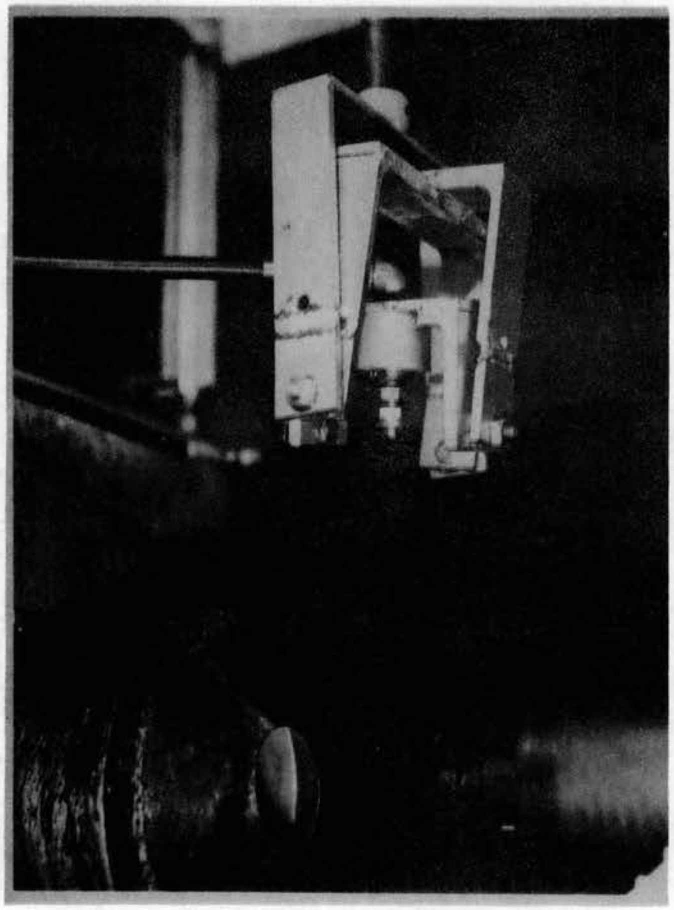


Fig. 7. Nozzle Holding and Positioning Device.

selected angles. An adjustable protractor-level was used to position the nozzle body to the nearest degree.

A fan type nozzle was selected for the development of a sampling procedure for the following reasons:

1. The fan nozzle is important in agricultural work.
2. Information relative to the drop size distributions of fan type nozzles is practically non-existent.
3. Much of the information relative to sampling fan nozzles would be applicable to cone type nozzles, though not necessarily vice-versa.

The spray nozzle used in these experiments was a Delavan type FS-2-65^o fan nozzle rated at 0.069 gallons per minute (water) at 40 pounds per square inch pressure.

Air pressure was used to move liquid through the atomizing device. A ten gallon pressure fluid tank (maximum working pressure of 110 pounds per square inch) equipped with a pressure regulator and agitator contained the liquid to be atomized. To avoid pressure fluctuations while sampling, air pressure to the regulator was supplied by a pressure storage tank. A portable air compressor was used to recharge the pressure storage tank. Liquid pressure near the nozzle was indicated by a 0-60 pounds per square inch pressure gauge. The gauge was separated from the nozzle by about 18 inches of flexible hose and was positioned at the same elevation as the nozzle.

Equipment for Laminar Flow Jet Stream Dispersion Experiments

The equipment used to conduct the laminar flow jet stream dispersion experiments is shown schematically in Fig. 8. A wood base provided support for the nozzle and pressure gauge, the collector tube, the condensate container and the spray collector. The entire assembly was placed in the spray chamber of the sampling apparatus in a position for sampling of the jet stream (Fig. 9). The collector tube was a six-inch length of 1.25 inch outside diameter (1.1875 inch inside diameter) aluminum tubing. The collector tube was insulated from the supporting bracket by 0.25 inch thick plastic strips cemented to the angle iron support. The horizontal jet stream discharged into a 12-inch length of six-inch diameter plastic tubing to which plastic fabric was attached in the form of a bag. A 0-15 pounds per square inch pressure gauge was mounted in a tee at the nozzle body to indicate pressure.

An inclined corrugated catchment surface 48 inches by 60 inches (Fig. 10) was used to collect the spray for dispersion pattern experiments. The catchment channels were 48 inches long and individual channels were one inch wide. Drops falling into the channels were collected in test tubes for weighing.

Nozzle equipment for these experiments consisted of a Delavan CS-1 cone nozzle and a Spraying Systems X-1 cone nozzle. With the swirl cores removed these nozzles provided circular orifices 250 (Delavan CS-1) and 530 (Spraying Systems X-1) microns in diameter.

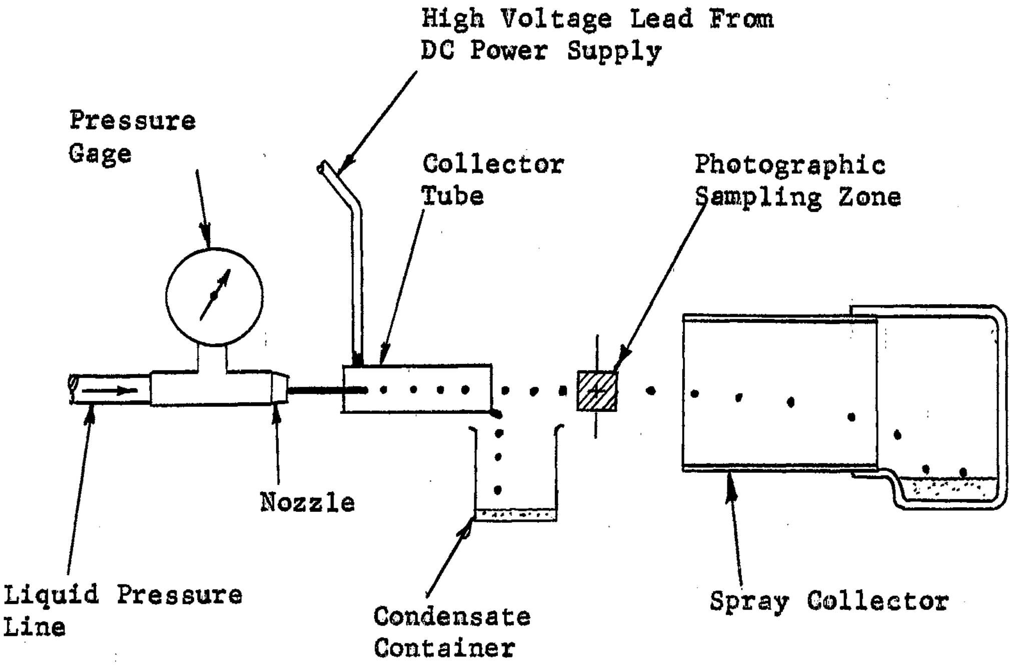


Fig. 8. Schematic Diagram of Laminar Flow Jet Stream Dispersion Apparatus.

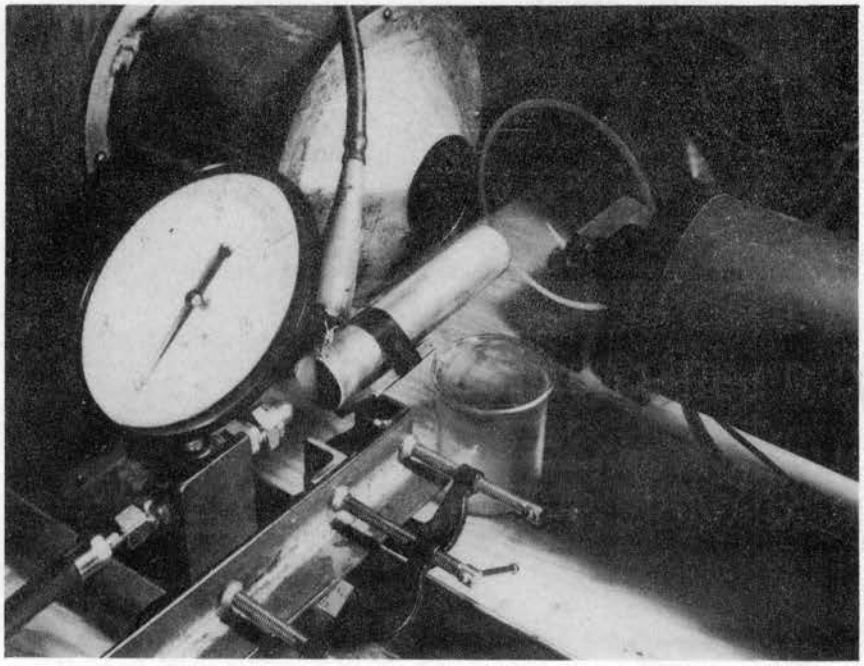


Fig. 9. Laminar Flow Jet Stream Dispersion Apparatus.

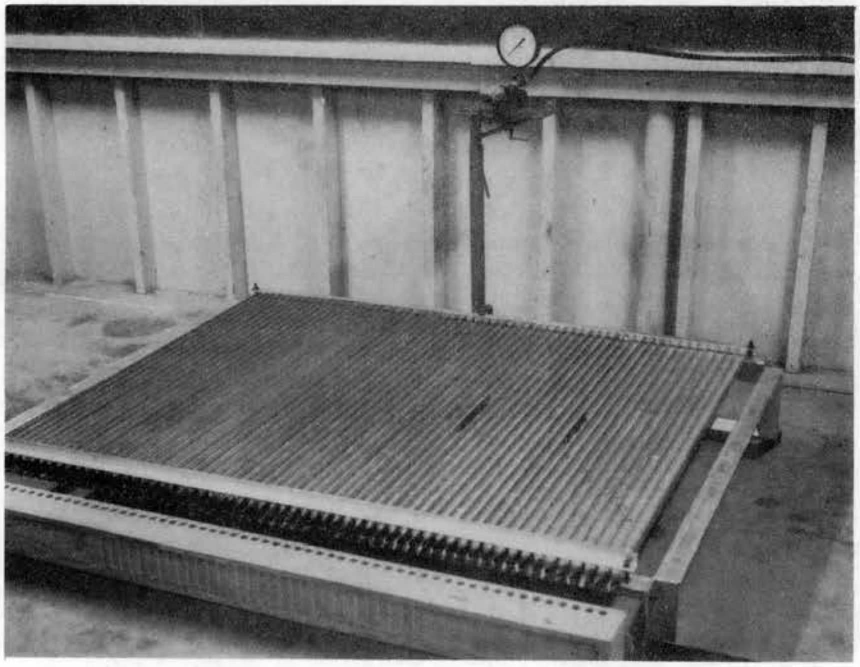


Fig. 10. Corrugated Catchment Surface and Setup for Dispersion Measurements.

A model KV30-5S Kilovolt Corporation DC power supply provided voltage to charge the collector tube. The output of this unit was continuously adjustable from 0-30 kilovolts with an overcurrent cutoff at five milliamperes.

Flow rate samples were timed using an electric clock and were weighed to the nearest 0.01 pound.

The liquid pressure system with the exception of the pressure gauge at the nozzle, was the same as used for the sample replication, distance and location experiments.

CHAPTER VI

EXPERIMENTAL PROCEDURE

The development of a sampling procedure involved the following questions:

1. Is it necessary or desirable to sample the entire spray pattern or just a part of it?
2. Exactly where in the spray pattern should the sample or samples be taken?
3. How many samples (replications) would be necessary to establish a reasonable level of confidence in the results?

The primary objective of sampling a spray is to obtain information about the size distribution of particles in the spray. This would suggest sampling all of the spray for drops to arrive at a drop size distribution for the entire spray pattern. For most of the sampling methods, however, and for the photographic method in particular, sampling all of the spray from an atomizer would involve a large number of individual samples and would most certainly be prohibitive in both time and money. Since most atomizers are designed to produce symmetrical spray patterns, using this pattern symmetry would greatly reduce the sampling effort with little or no reduction in sampling accuracy. However, pattern symmetry would need to be ascertained since very subtle irregularities in symmetrical orifices can produce relatively large changes in the spray pattern.

Sampling Location and Distance

Fan nozzles characteristically produce an elliptical wetted pattern on a surface perpendicular to the nozzle axis. For the nozzle selected, acceptable pattern symmetry was established by:

1. Stroboscopic observation for irregularities in the liquid configuration as it emerged from the orifice and disintegrated.
2. Examination of the symmetrical wetted pattern produced when spraying onto an absorbant surface.

Pattern symmetry having been established, samples could then be taken in one of the quadrants to completely describe the atomization pattern of the nozzle.

At some distance from an atomizer, the spray cloud may be considered to be in a relatively stabilized condition, i.e., the major changes in drop velocity have occurred, the atomization process has been completed (sheet-ligament breakup and any subsequent liquid-air impaction breakup) and the atomized particles have had time to reach a relatively stable shape configuration. Sampling in this zone might provide the most meaningful information concerning the true nature of the drop distributions. The distance from the atomizer to the sampling zone would vary depending upon the liquid pressure, atomizer type, and liquid physical properties. Further, drop dispersion is a function of distance from the atomizer and must be considered to obtain a satisfactory drop concentration for a sample.

Rather than conduct an experiment which would include all of the variables over all of the ranges that might be encountered in the future to be able to predict a desired sampling distance for any set of conditions, the following procedure was developed and followed to establish a desired sampling distance for each nozzle test condition:

1. Adjust spraying system to desired test conditions.
2. Using a stroboscope, examine the spray pattern and locate an area where atomization appears complete, i.e., where drop shapes appear relatively stabilized.
3. Starting from this point, take a series of replicated double exposure samples along a drop stream (where large drops are seen or are presumed to be) at intervals of one inch until dispersion causes the sample drop concentration to become unacceptable.
4. A first estimate of an appropriate sampling distance can be made by examining the drop velocity data to locate a sampling distance where the smaller drops have undergone major velocity changes. Adjustments to this estimate can then be made based on visual assessment of the drop velocity sample negatives for a sampling distance where both drop shape stability and the number of drops per sample are acceptable.

The nozzle orifice was positioned at the desired sampling distance vertically above the centerline of the camera. The nozzle was also positioned in the holder so the orifice would remain stationary with respect to the camera to provide a constant sampling distance for varying angular movements of the nozzle body. The plane containing the liquid sheet emerging from the nozzle was adjusted perpendicular to the camera axis and was carefully positioned in the plane of best focus.

A sampling pattern was established for one quadrant of the spray pattern from the nozzle for each test condition. Limits of the spray sampling pattern were determined by angular movement of the nozzle body in a plane perpendicular to and in a vertical plane passing through the camera axis until no drops appeared on the camera viewing screen under stroboscopic illumination. Since examination of the breakup of the liquid filament near the edge of the spray pattern was of great interest, this position was noted and arranged so that in sampling, drop images from this part of the spray would appear in focus at the center of a sample negative.

Two test conditions were established for sampling the drop size distributions occurring in a fan spray:

1. Tap water (with one per cent nigrosine dye to make the drops opaque) at 40 pounds per square inch pressure.
2. Number two diesel fuel at 20 pounds per square inch pressure.

Both liquids selected for these test conditions were common spray carrier materials. The operating pressures were established to represent typical operating pressures for these liquids and this nozzle. Measured values of surface tension and relative viscosity for the liquids can be found in Appendix A-II. A sampling distance and sampling pattern was determined for each test condition.

From a stroboscopic examination of the atomization, it appeared that the atomization of the water was complete at about two inches from the orifice. Starting at this point, replicated double exposure samples were taken along a drop stream to assist in establishing a desirable sampling distance. Samples were taken at distances of 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 8.5, 10.5 and 12.5 inches from the orifice with the nozzle body inclined 15 degrees from vertical in a vertical plane perpendicular to the camera axis. For this test condition, the camera was adjusted to provide a magnification of 10. The delay between flashes was adjusted to 25 microseconds for the double exposure samples.

The limits of the spray pattern of the nozzle when positioned at the desired sampling distance of six inches (see Chapter VII) above the centerline of the camera were observed when the nozzle was inclined 30 degrees from vertical in a vertical plane perpendicular to the camera axis and 12 degrees from vertical in a vertical plane passing through the camera axis. When the nozzle was inclined at 25 degrees the drops formed from the breakup of the liquid filament on the edge of the pattern appeared approximately in the center of the viewing screen.

The fine grid wire silhouettes that appeared on the sample negatives provided a convenient area four inches wide and two inches high for scanning. At a camera magnification of ten, the area in the spray sampled was 0.4 x 0.2 inches. At this magnification and with the lens iris adjusted to f/16, the effective depth of field was calculated and measured to be 0.045 inches. Thus, the spray drops occurring in a space measuring 0.4 x 0.2 x 0.045 inches were photographed for measurement.

From the spray pattern limits and the dimensions of the space volume sampled, the sampling pattern for one quadrant of the water spray containing 32 positions was established (Figs. 11 and 12). Sampling position number one was established with the nozzle body axis vertical and positioned to intersect the camera axis at the plane of best focus. From this position, rotation of the nozzle body axis through 5° in a vertical plane perpendicular to the camera axis caused sampling position number two to be oriented for sampling (photographing). Movement of the nozzle axis in 5° increments in this same plane caused positions 2, 3, 4, 5, 6, and 7 to be oriented for sampling. Other rows of sampling positions were oriented for sampling by rotating the nozzle axis through 3° increments in a vertical plane containing the camera axis.

The sampling distance and pattern was established for the diesel fuel spray in a similar manner. Replicated double exposure samples were taken along a drop stream at 3, 4 and 5 inches from the orifice with the nozzle body inclined 10 degrees from vertical in a vertical plane perpendicular to the camera axis. For this test condition, the camera was adjusted to a magnification of 8.0. The delay between flashes for the double exposure samples was 25 microseconds.

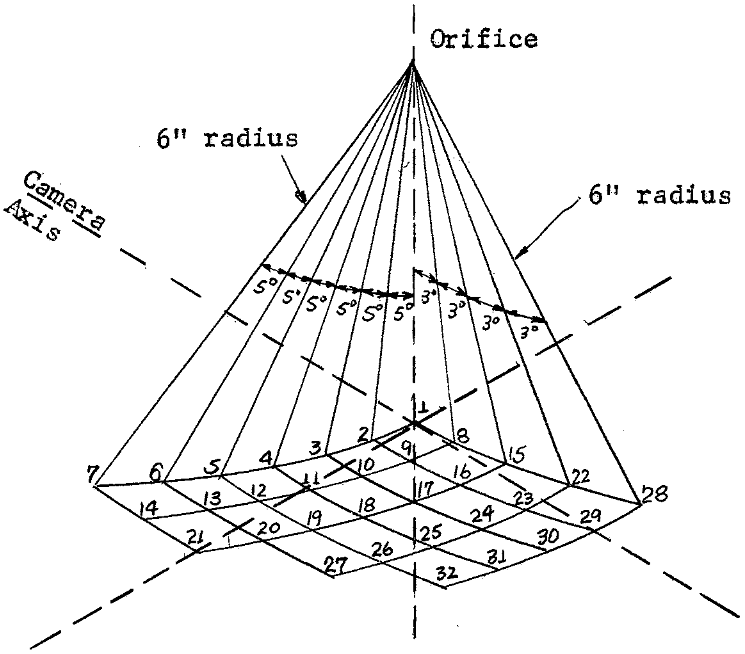


Fig. 11. Sampling Pattern for Water at 40 psi.

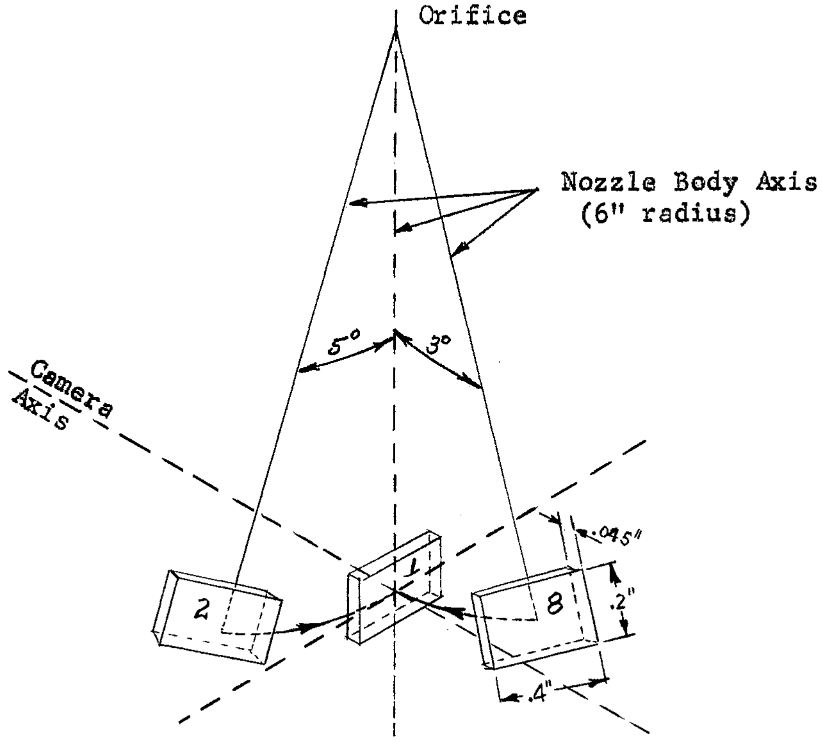


Fig. 12. Position of Adjacent Sampling Zones - Water at 40 psi.

The angular limits of the diesel fuel spray pattern when positioned four inches above the centerline of the camera (the desired sampling distance - see Chapter VII) were observed when the nozzle body was inclined about 25 degrees from vertical in a vertical plane perpendicular to the camera axis and at 18 degrees from vertical in a vertical plane along the camera axis. The breakup of the edge of the spray pattern appeared in the center of the viewing screen when the body was inclined at 18 degrees from vertical in a vertical plane perpendicular to the camera axis. At a camera magnification of eight, considering a four inch by two inch negative scanning area, the area of spray sampled measured 0.5 by 0.25 inches. The change in camera magnification did not measurably change the effective field depth. Thus, the spray drops occurring in a space measuring 0.5 by 0.25 by 0.045 inches were photographed for measurement.

From the spray pattern limits and the dimensions of the space volume sampled, the sampling pattern for one quadrant of the diesel fuel spray containing 32 positions was established (Figs. 13 and 14). As with the other test condition, the sampling positions were obtained by rotating the nozzle body axis in 6°increments in a vertical plane perpendicular to the camera axis and in 3° increments in a vertical plane containing the camera axis.

For both test conditions, sampling locations in the pattern were considered sufficiently close to provide continuous information concerning changes in distributions from one part of the pattern to another. Particular care was taken to locate the sampling position

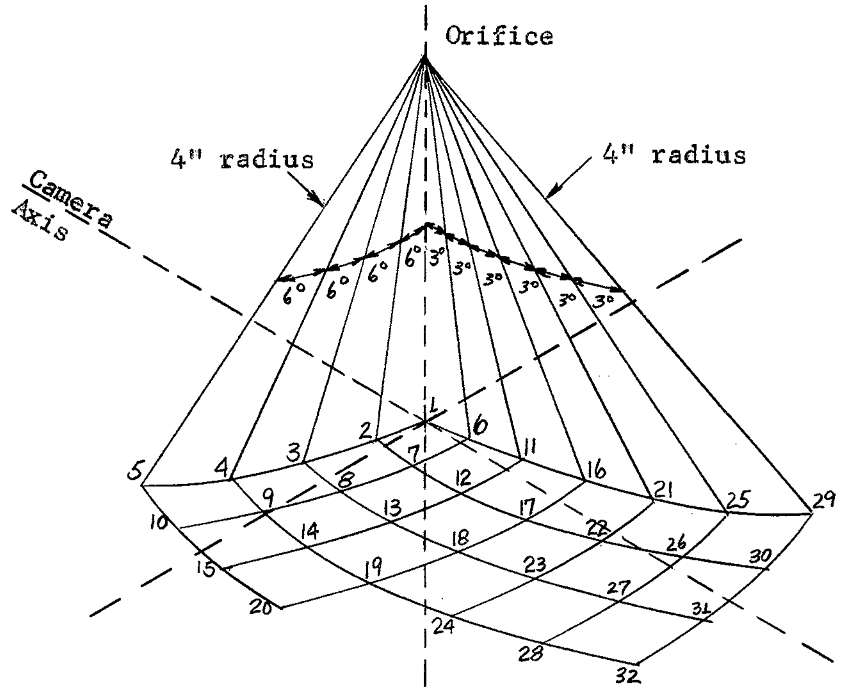


Fig. 13. Sampling Pattern for Diesel Fuel at 20 psi.

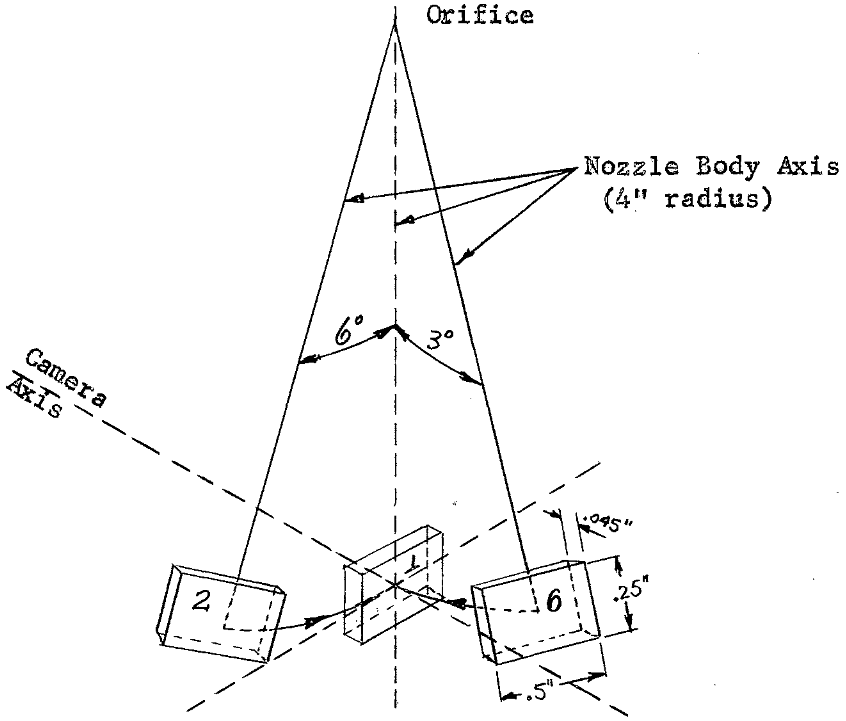


Fig. 14. Position of Adjacent Sampling Zones-Diesel Fuel at 20 psi.

where a great change was expected, i.e., the breakup of the liquid filaments at the edge of the liquid sheet. Since a degree of symmetry was established and assumed, samples in particular locations in the quadrant sampled were considered representative of similar locations in the other quadrants.

The same general procedure was used to arrive at a sampling location for the laminar flow jet experiments. In this case, the sampling distance was determined solely by stroboscopic examination of the jet stream breakup. Many of the smaller drops were observed to have appreciable velocity components causing them to move perpendicular to the jet axis. Thus, sampling had to occur before these drops were able to move out of the focus field of the camera. On the other hand, a greater sampling distance would allow more time for the drops to assume a stable shape configuration. Since samples of the laminar flow jet stream breakup were taken before appreciable drop dispersion had occurred, the entire pattern was sampled with one position of the orifice with respect to the camera.

Sample Replication

A procedure was developed to assist in determining the number of sample replications necessary to establish a reasonable level of confidence in the data.

It was recognized that the disintegration into drops of a small mass of liquid emerging from some part of an orifice at any moment was not a predictable process. The effects of liquid and ambient air turbulence, liquid physical properties, orifice configuration and other factors on this process have been stated in general terms individually but have not been related quantitatively. Unpredictable as individual disintegrations may be, predictable atomization patterns for all of the liquid from an orifice can be established. The volume distribution of a spray nozzle, for example, is easily obtained and reproduced. Since this distribution reflects the accumulation of drops at different locations in a spray pattern and is, within limits, predictable, the variation among the individual disintegrations at a particular location would not appear to be unusually large. It is an estimation of this variation that is sought to help in determining a desired number of sample replications. Because of the reproducibility of the volume distribution from a spray nozzle, it might reasonably be assumed that the variations in disintegrations for most locations in a spray pattern would not differ greatly. This assumption would enable characterizing the disintegration variation of an entire spray pattern by samples taken at a single location within the pattern.

Since a sample would consist of a number of drops of different sizes, a mean drop diameter might be computed, using data obtained from a particular location, that would characterize the atomization that had occurred. The mean drop diameters calculated from a number of different samples taken at the same location could then be subjected to a statistical analysis to obtain an estimate of the population standard deviation. Using equation 6-1 (66), the number of samples can be calculated that will estimate the true mean for a specified allowable error in the mean with a five per cent risk that the error will exceed the specified allowable error.

$$N = \frac{4S^2}{L^2} \qquad 6 - 1$$

N = number of samples

S = estimate of population standard deviation

L = allowable error in the sample mean

Since the volume distribution would be of particular interest in subsequent sampling, the volume mean diameter was selected from the several mean diameters to characterize the atomization at a particular location. For a discrete number of size classes, the volume mean diameter is calculated as follows:

$$\bar{x}_v = \sqrt[3]{\frac{\sum_{i=1}^{k} (x_i^3)\,(N_i)\,(\Delta x_i)}{\sum_{i=1}^{k} (N_i)\,(\Delta x_i)}} \qquad 6 - 2$$

i = number of size class

k = number of size classes

x_i = average diameter of size class

Δx_i = size class increment

N_i = number of drops in the i^{th} size class

For initial sample size determinations with the fan nozzle spraying water at 40 pounds per square inch, the number of samples taken at a selected location was arbitrarily established as about 15.

The sampling location for this test condition was also rather arbitrarily determined. Samples were taken about 4.25 inches from the orifice with the nozzle body inclined 10 degrees from vertical in a vertical plane perpendicular to the camera axis. At the time these samples were taken, the desired sampling distance had not been established and the distance used (4.25 inches) was based entirely on drop shape stability and sample concentration. For the diesel fuel at 20 pounds per square inch test condition, the fan nozzle body was inclined 10 degrees from vertical in a vertical plane perpendicular to the camera axis with the samples being taken four inches from the orifice.

Sample replication data was obtained in a similar manner for the breakup of laminar flow jet streams. Samples were taken 2.25 inches from the Delavan CS-1 nozzle (with core removed) operated at three pounds per square inch pressure and discharging water horizontally. Because of the small amount of dispersion that had occurred at this sampling distance, the entire pattern was sampled for a single orifice position.

Laminar Flow Jet Dispersion

All of the drop production methods reviewed allow the formation of liquid sheets and/or filaments which, upon disintegrating, form a range of drop sizes. The extent of the drop size range depends to a large degree on the turbulent state of the liquid as it emerges from an atomizing device. The use of viscous materials and particulating agents appears to offer the best solution for reducing the small drop component of sprays produced under turbulent flow conditions.

A laminar flow jet stream emerging from a simple circular orifice will disintegrate predictably into relatively uniform large drops about twice the orifice diameter and a few small drops irregularily interspersed between the large drops. The volume of the small drops found under laminar flow conditions has been found (65) to be two per cent or less of the total volume of liquid emerging from an orifice. The elimination of these small drops from the laminar flow jet breakup would result in a spray composed of uniform drops of a predictable size.

The work of Goyer, et. al. (60) would suggest that in passing a jet stream through an electric field sufficient electrical charge could be induced on the drops to make electrostatic forces predominate in the behavior of the drops and create a means by which the small drops could be separated from the large. Stroboscopic examination of a laminar flow jet stream passing through an electric field provided the following observations:

1. Under certain field conditions and position of the jet stream in relation to the field, the large and small drops could be separated into two distinct drop streams.
2. Under stroboscopic examination it appeared that the large drops were measurably smaller and more uniform in size as a result of passing through the electric field.
3. All drops emerging from the electric field had been charged

sufficiently to be mutually repelled and caused a considerable increase in the drop dispersion pattern over that produced by uncharged drops.

These observations led to the following propositions:

1. The separation of drops into two size streams would suggest one means of removing the small drops.
2. If in passing through an electric field the atomization of a jet stream was altered to such an extent that drops formed were smaller than would normally form, larger orifices could be used to produce a given drop size.
3. The induction of a surface charge of the same polarity on all drops in a spray would provide a means of producing a degree of dispersion (by mutual repulsion) not possible with uncharged drops and would permit uniform application with wider nozzle spacings.
4. The induction of a surface charge on drops opposite in polarity to the majority charge on objects to be sprayed would increase the drop impaction efficiency.

The first three of these propositions were considered as being related to the problem of producing a homogeneous spray. An experiment was designed to yield the following information:

1. Changes in drop size and uniformity attributed to passing a laminar flow jet stream through an electric field.
2. The effectiveness of a charged conductor surrounding a laminar flow jet stream in collecting the small drops

created in the breakup.

3. Changes in the dispersion pattern caused by passing a laminar flow jet stream through an electric field.

The apparatus consisted of a laminar flow circular jet discharging horizontally through an insulated cylindrical tube, to which a high voltage DC electrode was attached (Figs. 8, 9). Samples were taken as the drops emerged from the tube to determine the size, shape and relative quantities of large and small drops. At this sampling location, the drop dispersion was such that the entire atomized stream could be sampled in one sampling position. The drops impacting on the inside of the tube were also collected to obtain a measure of the effectiveness of the tube in collecting the small charged drops.

The following specific test conditions were established:

1. Horizontal laminar flow jets 250 and 530 microns in diameter operated at 3 psi and 1 psi, respectively, atomizing tap water.
2. Aluminum collector tube 1.25 inches outside diameter, 1.1875 inches inside diameter, 6 inches long, with the entrance end one inch from the orifice.
3. Two voltage levels for each orifice; 0 and 1 KV for the 250 micron orifice; 0 and 2 KV for the 530 micron orifice.
4. Negative electrode polarity.

Separate experiments were conducted for the two orifice sizes each at two voltage levels. The procedures established for determining sample location and replication were followed. Six 30 minute tests were made with each orifice using voltage applied to the collector tube to determine the amount of liquid collected in the tube and the amount passing through the tube.

Five tests were made with each orifice, with and without voltage applied to the collector tube, to determine the dispersion patterns of the charged and uncharged jet streams. The horizontal orifice axes were positioned 24 inches above the catchment surface (Fig. 10) and were aligned parallel to the channels. The orifices were located 20 inches (250 micron orifice at 3 psi) and 9 inches (530 micron orifice at 1 psi) horizontally from the ends of the channels.

Procedure Used in Sampling

The following general procedure was established for taking samples with the photographic apparatus to insure consistency of sampling:

1. Before each test series, check and adjust camera magnification to desired value.
2. Turn on flash units and allow to warm up. Adjust sensitivity and check consistency of flash by triggering units several times with camera shutter.
3. Place liquid in pressure fluid tank, check liquid and air connections, and charge storage tank with air from air compressor.
4. Install atomizer and position for appropriate sampling distance.

5. Position stroboscope for illuminating the sampling area, open camera shutter and with system operating at test pressure, adjust center of atomizer stream in plane of best focus. Clamp in position.
6. Turn pressure off. Remove extension tubes and cover from camera lens and clean lens. Adjust lens iris to proper setting and replace extension tubes and cover.
7. Close camera shutter and remove stroboscope.
8. Adjust flash delay if needed.
9. Turn pressure on and adjust to test pressure.
10. Adjust atomizer to desired sampling location position.
11. Insert film holder in camera and remove dark slide.
12. Record film holder number and test condition.
13. Check nozzle pressure and other test conditions, remove extension tube cover, take picture, replace extension tube cover, replace dark slide. (At the very beginning of each test series, the photographic process was checked using Polaroid film.)
14. Turn pressure off.
15. Repeat steps 8 - 14 for all samples taken in each series.
16. After each six photographs, turn off pressure and clean camera lens.
17. Recharge air storage tank from compressor when pressure drops below 50 pounds per square inch.

CHAPTER VII

PRESENTATION AND ANALYSIS OF DATA

Sampling Location and Distance

One of the factors given consideration in the selection of a desirable sampling distance was the drop velocity as related to distance from the orifice. Tables I and II show the average drop velocities for the fan nozzle test conditions. The numbers shown for each sampling distance are averages of the velocities for each drop size class found on from four to six negatives. Drop velocities were obtained from the original data (Appendix C) using the following formula:

$$V = \frac{(GM)(GC) \times 10^5}{(D)(M_1)(M_2)} \qquad 7 - 1$$

V = average drop velocity (cm/sec)

GM = drop movement (comparator grid chart reading)

GC = grid chart constant (mm/grid chart unit)

D = flash delay (microseconds)

M_1 = camera magnification

M_2 = comparator magnification

The average velocities measured nearest the orifice correspond to calculated values of the theoretical velocity of discharge from

TABLE I

AVERAGE DROP VELOCITIES (CM/SEC) AT VARYING DISTANCES FROM ORIFICE - WATER AT 40 PSI

DELAVAN FS-2-65°

Drop Size Range (Microns)	Distance from Orifice (inches) 1.5	2.5	3.5	4.5	5.5	6.5	8.5	10.5	12.5
1-25	*	*	340	320	*	*	280	*	*
26-50	1419	849	503	421	310	320	257	160	40
51-75	1720	1109	780	667	480	287	230	187	200
76-100	1706	1428	1240	1104	*	487	256	120	240
101-125	1776	*	1280	1013	960	907	667	*	*
126-150	1768	1609	1600	1300	*	1000	720	536	*
151-175	1840	1800	1520	1450	1200	*	*	*	*
176-200	1747	1800	*	1480	1540	*	*	*	*
201-225	1600	*	*	*	*	*	*	*	*
226-250	1760	1640	*	*	*	*	*	*	*
251-275	*	1840	*	*	*	*	*	*	*

* No drops were found for velocity measurement.

TABLE II

AVERAGE DROP VELOCITIES (CM/SEC) AT VARYING DISTANCES FROM ORIFICE - DIESEL FUEL AT 20 PSI

DELAVAN FS-2-65°

Drop Size Range (Microns)	Distance From Orifice (inches) 3	4	5
1-25	1467	*	550
26-50	1243	386	411
51-75	1321	588	525
76-100	1443	880	655
101-125	1350	992	813
126-150	1371	1065	942
151-175	1229	1467	1000
176-200	1100	*	1300

* No drops were found for velocity measurement.

an orifice. It should be noted that an attempt was made to measure only those drop pairs on the double exposure negatives appearing to be in the same degree of focus. Drops having appreciable velocity components perpendicular to the camera plane of best focus would move toward or away from the plane of best focus during the double exposure interval and cause a change in the sharpness of the image from one exposure to the next. Velocity measurements made from the negatives without regard for change in image sharpness would tend to underestimate the actual drop velocity.

Incomplete data on the velocities of the drops, particularly the larger drops at the greater distances, was due to the low frequency of occurrence of certain drop sizes in the distribution and the dispersion of the spray which reduced the number of drops photographed per sample.

An inspection of the velocity data for water at 40 psi (Table I) showed that major changes in drop velocity for most drop sizes had occurred at 4.5 to 5.5 inches from the orifice. However, at these distances the drops had not yet assumed a shape configuration suitable for accurate size measurement. An inspection of the sample negatives showed that at 5.5 to 6.5 inches, the drop images had assumed a circular shape and were sufficiently stabilized for measurement. Also, at sampling distances greater than 6.5 inches, the number of drops occurring in each sample was considered inadequate to obtain a representative sample of the spray at a particular location without requiring a large number of sample replications. Since the spray drops appeared to be in a relatively stable condition at 5.5 to 6.5

inches and the drop concentration per negative was considered acceptable, a sampling distance of six inches was selected for the water spray at 40 psi. This distance was considered the maximum distance to provide an acceptable number of drops per sample and the minimum distance that would provide acceptable drop shape stability under these conditions.

The desired sampling distance for the diesel fuel spray was established in a similar manner. From an inspection of the diesel fuel velocity data (Table II) and a visual assessment of the drop configuration and concentration from the sample negatives, four inches was selected as an appropriate sampling distance for the diesel fuel spray at 20 psi.

Sample Replication

The volume mean drop diameters calculated from 15 samples taken at the same location in the pattern of the fan nozzle spraying water at 40 psi are shown in Table III. Each volume mean diameter was calculated from all of the measurable drop images found on a single sample negative (Appendix D). The drop images appearing on each negative were sorted into 25 micron size classes, i.e., 1-25, 26-50, 51-75, etc. Since the smallest drop that could be measured was approximately 12.5 microns in diameter, two times the smallest drop size was considered a reasonable drop size range. Equation 6-2 was used to calculate the volume mean diameters.

The standard deviation for these mean diameters was calculated to be 10.8 microns. This value was used as an estimate of the

TABLE III

VOLUME MEAN DROP DIAMETERS FOR WATER AT 40 PSI

Negative Number	Volume Mean Diameter (Microns)
2	64.3
3	88.2
4	70.2
7	83.7
8	61.4
9	72.8
13	67.2
14	94.1
17	63.6
18	73.9
19	70.1
21	72.1
22	93.5
23	68.4
24	84.6
Average	75.2
Standard Deviation	10.8
Coeff. of Variation	14.4%

population standard deviation in equation 6-1 to calculate the number of replications for a specified allowable error in the sample mean.

The selection of an allowable error in the sample mean was a rather arbitrary proposition. However, based on the limits of drop size measurement, the rather arbitrary size class increments established, and considering the coefficient of variation (14.3%), an estimation of the true volume mean diameter within ±12 microns (about half the size class increment) was not considered an unreasonable choice. For these values the minimum number of replications was calculated to be four.

Similar consideration and treatment was given to the volume mean diameters calculated from 14 samples taken at the same location in the pattern of the same fan nozzle spraying diesel fuel at 20 psi (Table IV). Although the volume mean diameter averaged about 10 microns smaller than for water, the standard deviation (9.5 microns) and the coefficient of variation (14.7%) were almost the same as for water. With an allowable error in the sample mean of ±12 microns, and an estimate of the population standard deviation of 9.5 microns, the minimum number of replications was calculated to be three.

Eight samples were taken of the atomization of a laminar flow jet stream to provide an estimate of the number of replications for these experiments. The data taken for the Delavan CS-1 nozzle (with core removed) discharging water at 3 psi is summarized in Table V.

Considering this spray to be composed of essentially two drop sizes (large and small drops) and because of the small influence of

TABLE IV

VOLUME MEAN DROP DIAMETERS FOR DIESEL FUEL AT 20 PSI

Negative Number	Volume Mean Diameter (Microns)
1	62.1
2	66.6
3	50.2
5	64.9
6	51.8
7	55.0
8	72.0
10	57.0
11	75.8
12	77.3
14	68.2
16	54.0
17	69.8
18	77.4
Average	64.4
Standard Deviation	9.5
Coeff. of Variation	14.8%

TABLE V

AVERAGE DIAMETERS AND NUMBERS OF DROPS FROM LAMINAR FLOW JET (DELAVAN CS-1 AT 3 PSI)

Negative Number	Ave. Drop Dia. (Microns) Large	Small	No. Drops Per Sample Large	Small
1	580.5		9	0
2	584.1		8	0
3	582.1	212.4	8	1
4	605.9	204.1	8	2
5	634.0	124.9	8	1
6	578.6	143.7	9	2
7	592.9	143.7	7	2
8	586.0		8	0
Average	593.0	165.0	8.1	1.0

the small drops on the volume mean diameter, the length mean diameters of the large drops were used in the estimation of the number of replications (the volume mean diameter reduces to a length mean diameter when there is but one drop size class).

The standard deviation for the length mean diameters of the large drops was calculated to be 18.7 microns. With an allowable error in the sample mean of ±12 microns, the minimum number of replications was established as nine.

Drop Size Distributions in a Fan Spray

The spray from one section of a fan nozzle pattern was sampled for the drops occurring in the spray. These data were used:

1. To describe the spray characteristics in a fan spray.
2. To locate sampling positions in the spray pattern where the drop distributions would be characteristic of the drop distributions of the entire spray pattern.

Original data for the two sampling conditions (water at 40 psi and diesel fuel at 20 psi) are presented in Appendix E. The number of drops found in each of the 20 size classes for 32 sampling locations are also presented in tabular form in Appendix E. The range of drop sizes for each size class is shown in Table VI.

The cumulative volume distributions for each sampling position in the water and diesel fuel sprays are presented in Figs. 15 to 26. Superimposed on each graph is a composite cumulative distribution which includes all of the drops found in all of the sampling positions

TABLE VI

THE RANGE IN DROP SIZES FOR THE 20 SIZE CLASSES USED

Drop Size Class	Drop Size Range (Microns)
1	1-25
2	26-50
3	51-75
4	76-100
5	101-125
6	126-150
7	151-175
8	176-200
9	201-225
10	226-250
11	251-275
12	276-300
13	301-325
14	326-350
15	351-375
16	376-400
17	401-425
18	426-450
19	451-475
20	476-500

for each test condition. The composite cumulative volume distributions shown in tabular form in Table VII were considered representative of the entire spray. No attempt was made to fit a particular distribution function to these data. The graphs are presented to show the nature of the distributions from point to point in the spray pattern.

The volume mean diameters were calculated for each sampling position for both test conditions and are presented in Tables VIII and IX. The numbers are arrayed in the tables in the same relative position as in the sampling pattern (see Figs. 11 and 13).

Reference to the cumulative distributions and volume mean diameters showed that large changes in the drop distributions did not occur over most of the spray pattern for the fan nozzle. Around the outside edge of the pattern, however, the range in drop sizes was smaller and the volume mean diameter tended to be slightly larger than at positions in the central portion of the pattern. In one sampling area (positions 6, 7, 13, 14 for the water data and position 4 for the diesel fuel data) relatively large drops were found. Because of their size, even though the numbers were small, these large drops represented a sizable fraction of the total volume of the spray. Large volume mean diameters were calculated for several other sampling positions near the edge of the pattern, especially for the water data. These large mean diameters were generally the result of a large drop being found in samples containing a small number of smaller drop sizes. The calculated volume mean diameter for these samples would, then, be very nearly the diameter of the large drop measured in the sample.

TABLE VII

COMPOSITE CUMULATIVE VOLUME DISTRIBUTIONS FOR FAN NOZZLE TEST CONDITIONS

Drop Size Class	% by Volume Smaller Than Size Class Water at 40 psi	Diesel Fuel at 20 psi
1	0.03	0.06
2	1.92	2.25
3	11.55	14.03
4	28.56	22.61
5	45.03	30.18
6	55.43	34.51
7	62.85	38.09
8	72.11	42.16
9	76.26	43.94
10	92.18	44.77
11	94.13	47.00
12	96.70	49.20
13	100.00	52.03
14		55.59
15		60.01
16		67.19
17		75.86
18		86.21
19		89.26
20		100.00

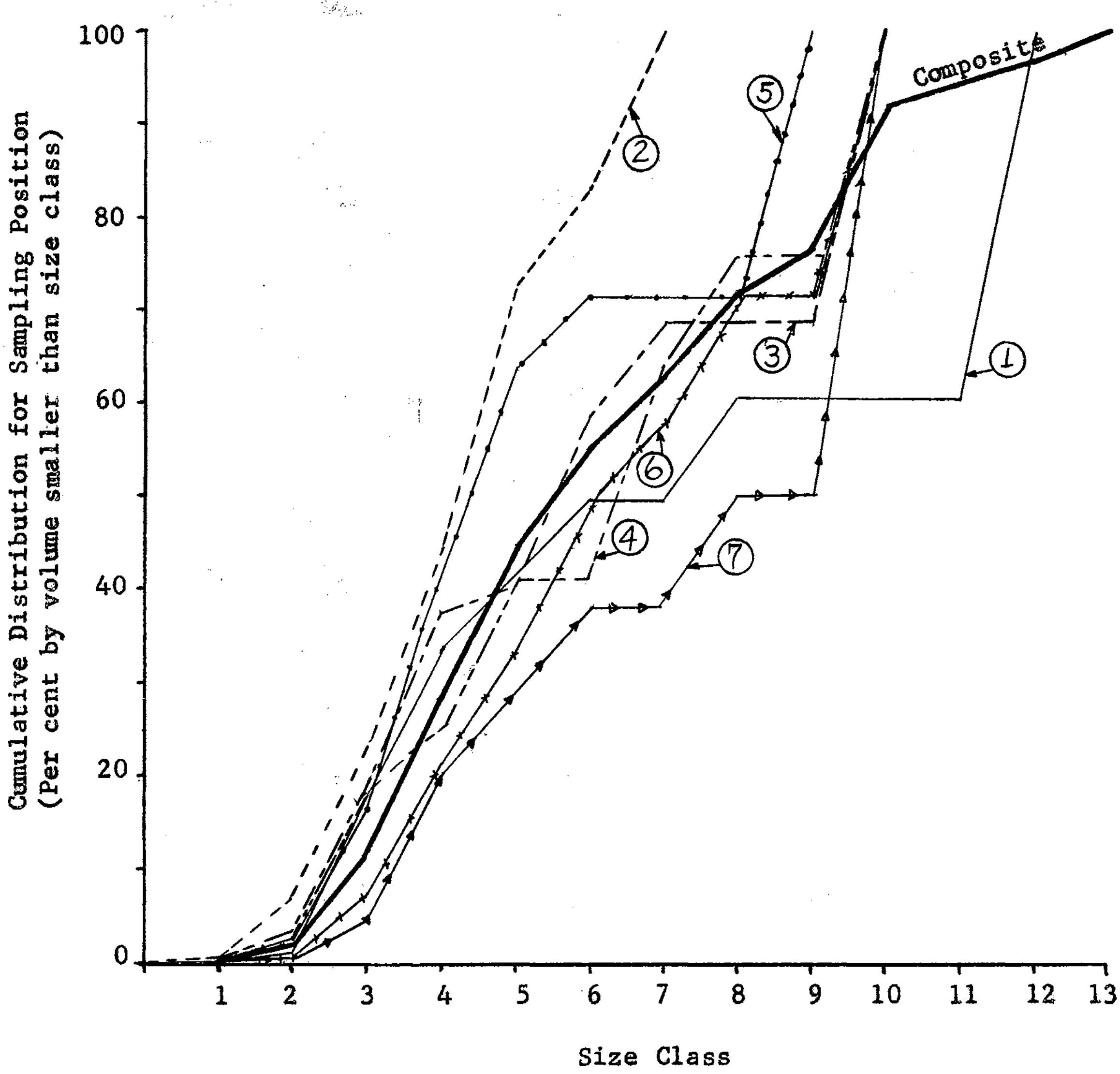


Fig. 15. Cumulative Volume Distributions (Positions 1-7) for Water at 40 psi.

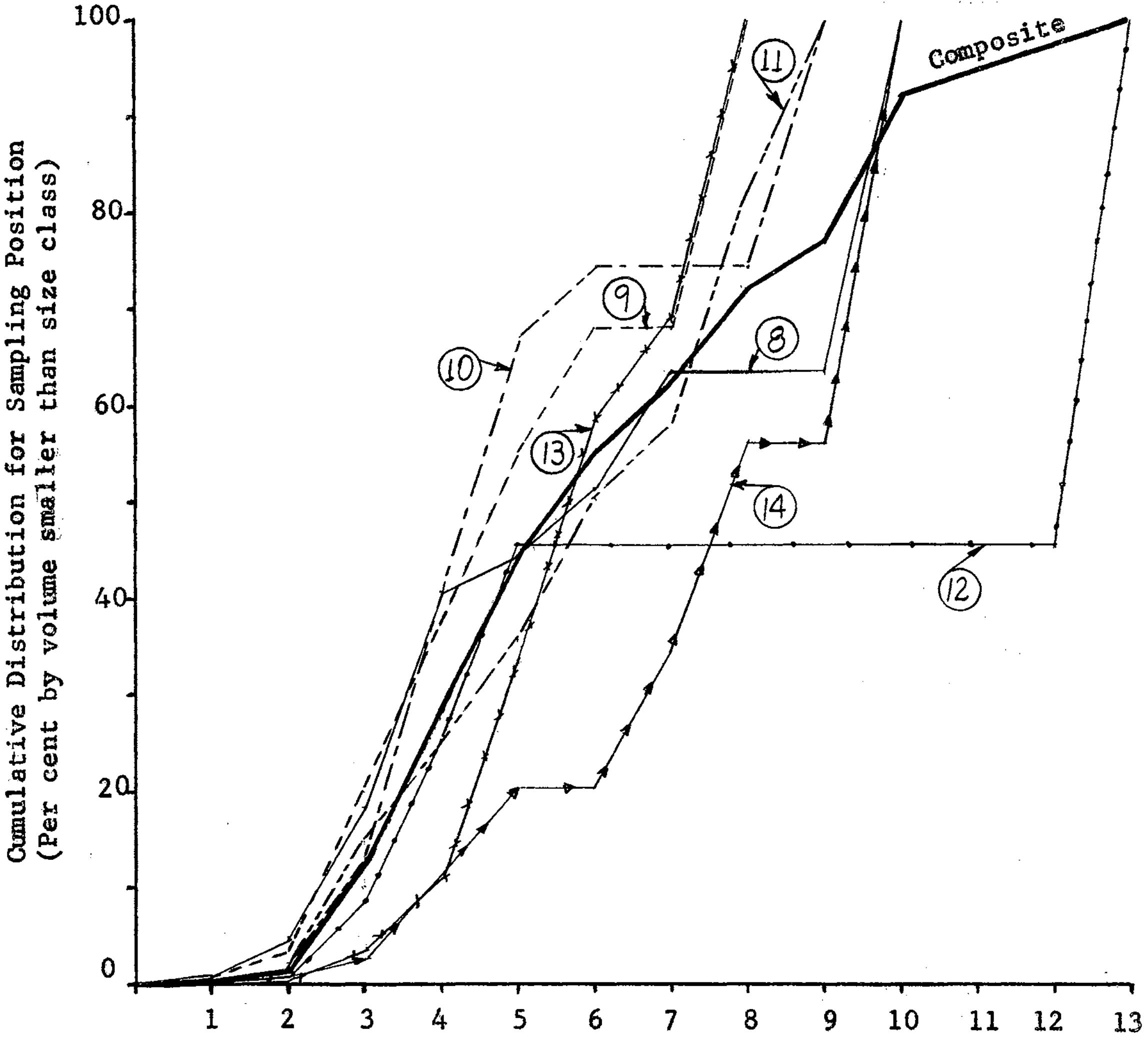


Fig. 16. Cumulative Volume Distributions (Positions 8-14) for Water at 40 psi.

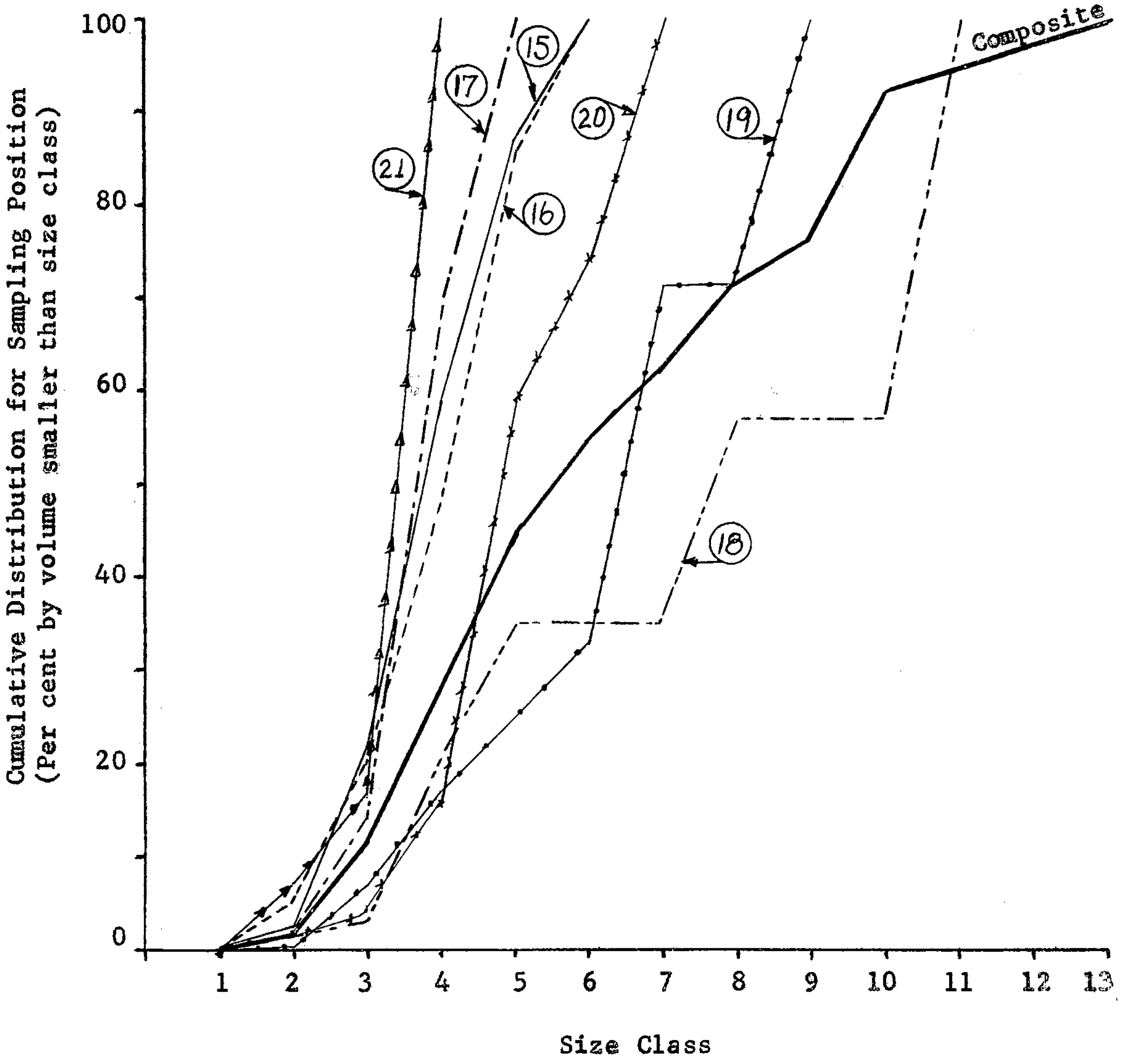


Fig. 17. Cumulative Volume Distributions (Positions 15-21) for Water at 40 psi.

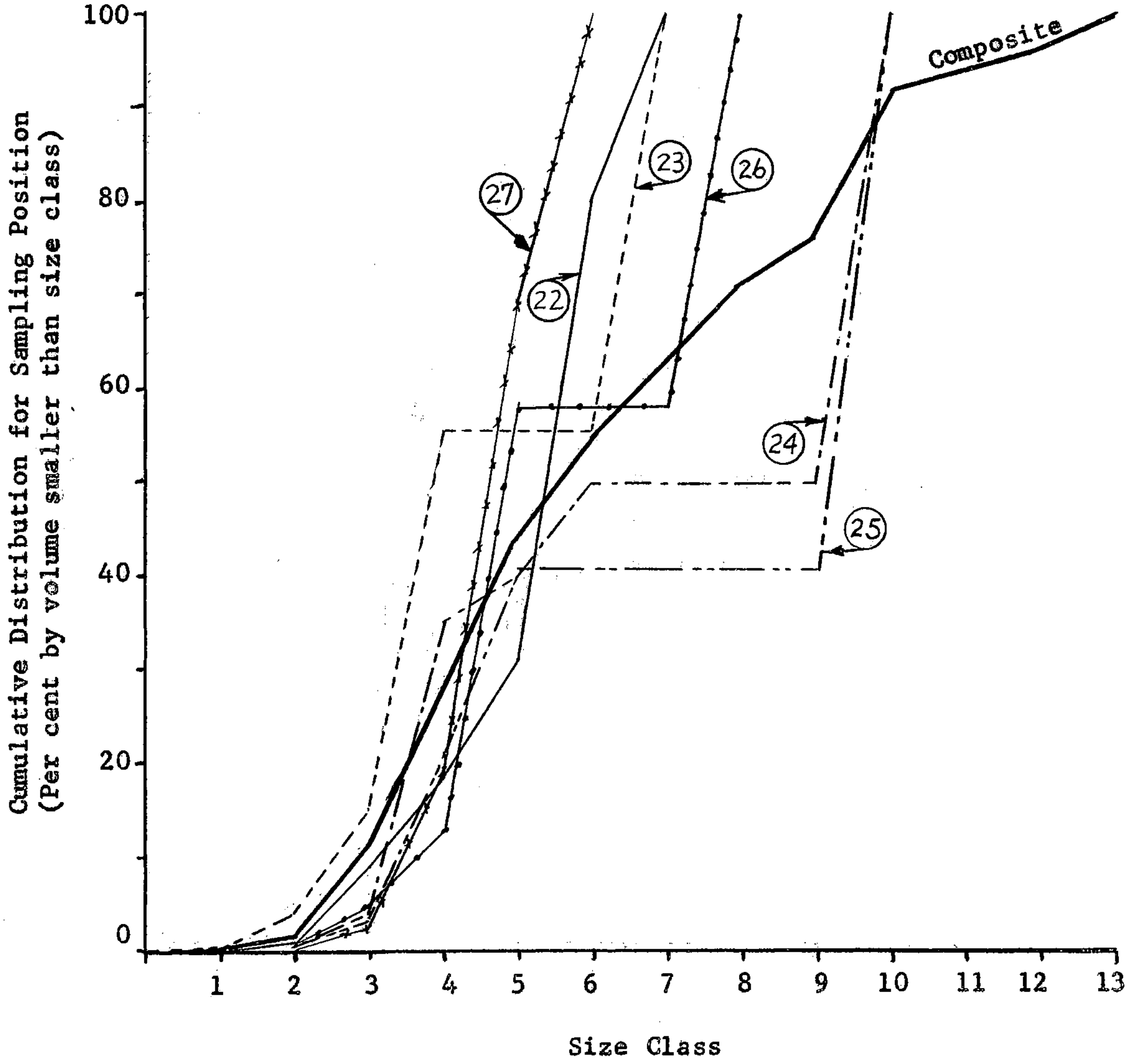


Fig. 18. Cumulative Volume Distributions (Positions 22-27) for Water at 40 psi.

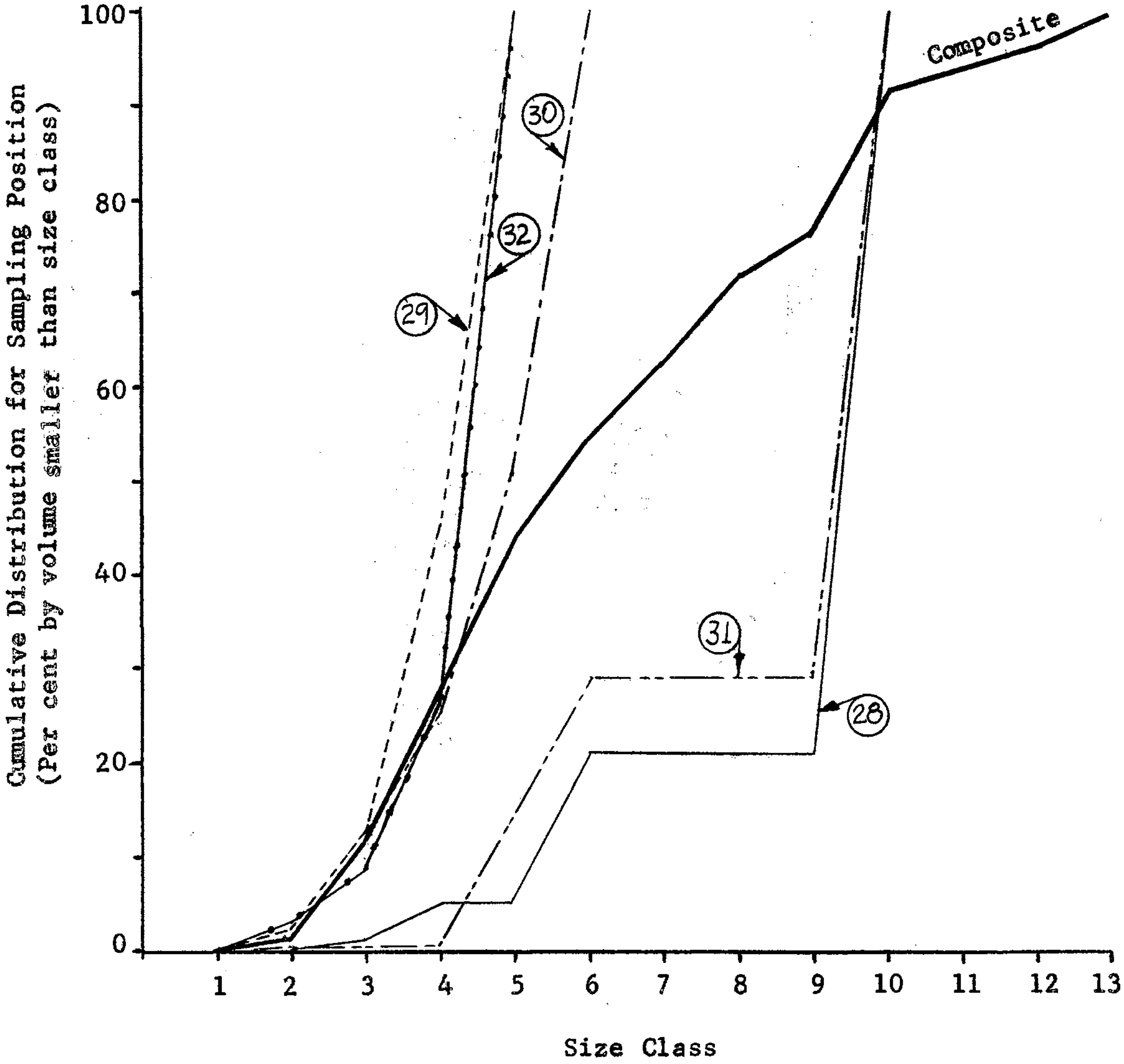


Fig. 19. Cumulative Volume Distributions (Positions 28-32) for Water at 40 psi.

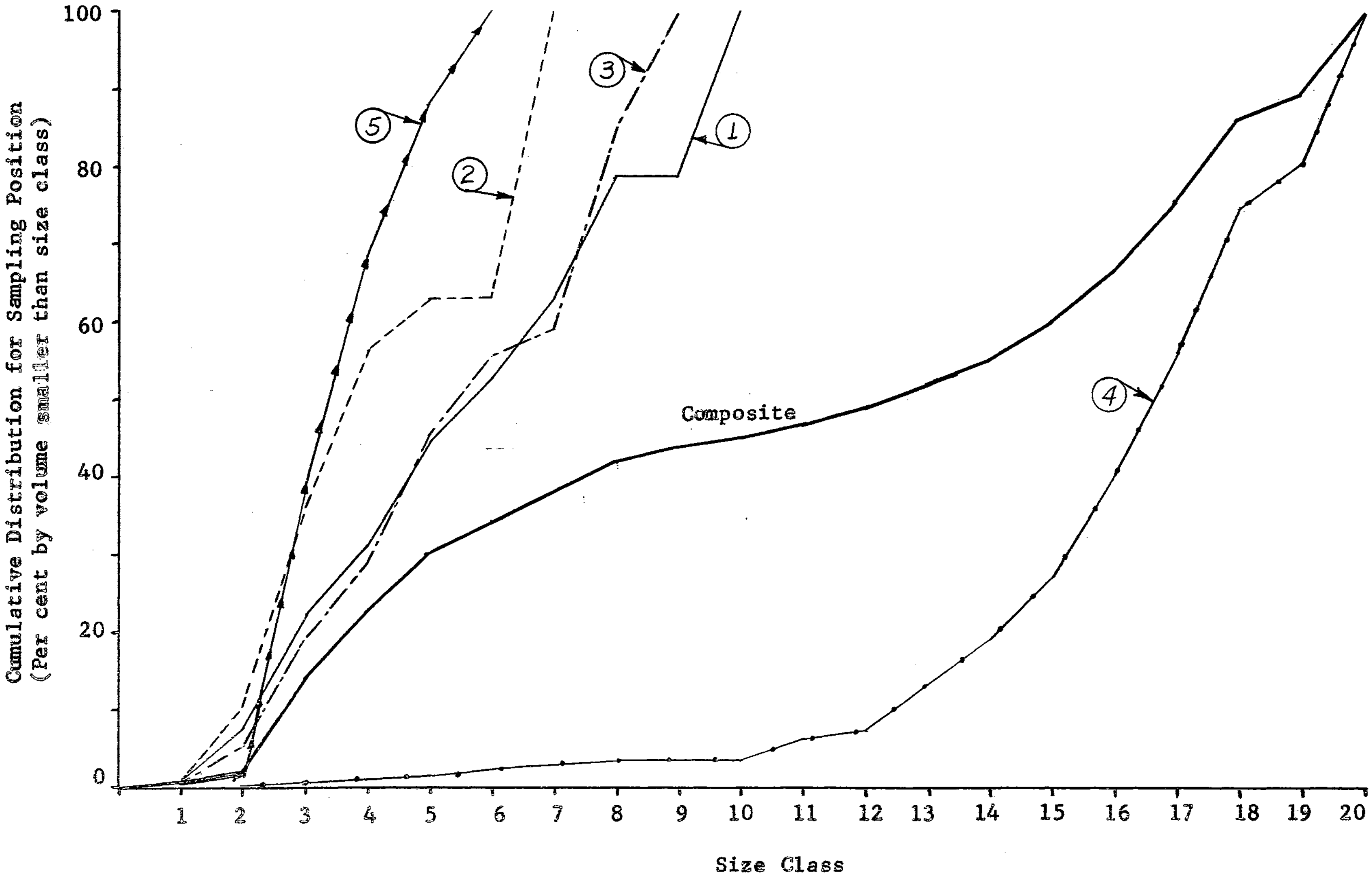


Fig. 20. Cumulative Volume Distributions (Positions 1-5) for Diesel Fuel at 20 psi.

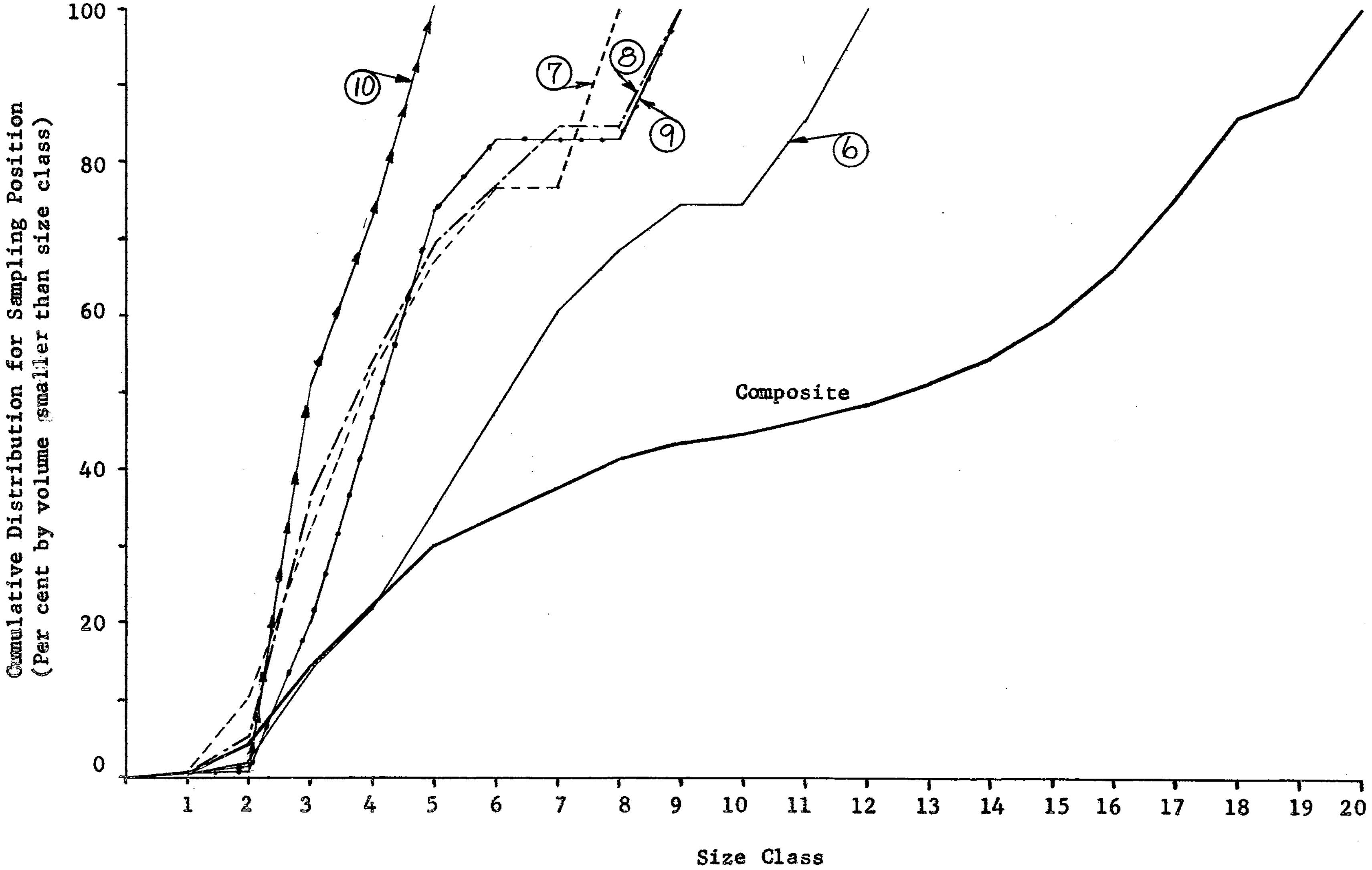


Fig. 21. Cumulative Volume Distributions (Positions 6-10) for Diesel Fuel at 20 psi.

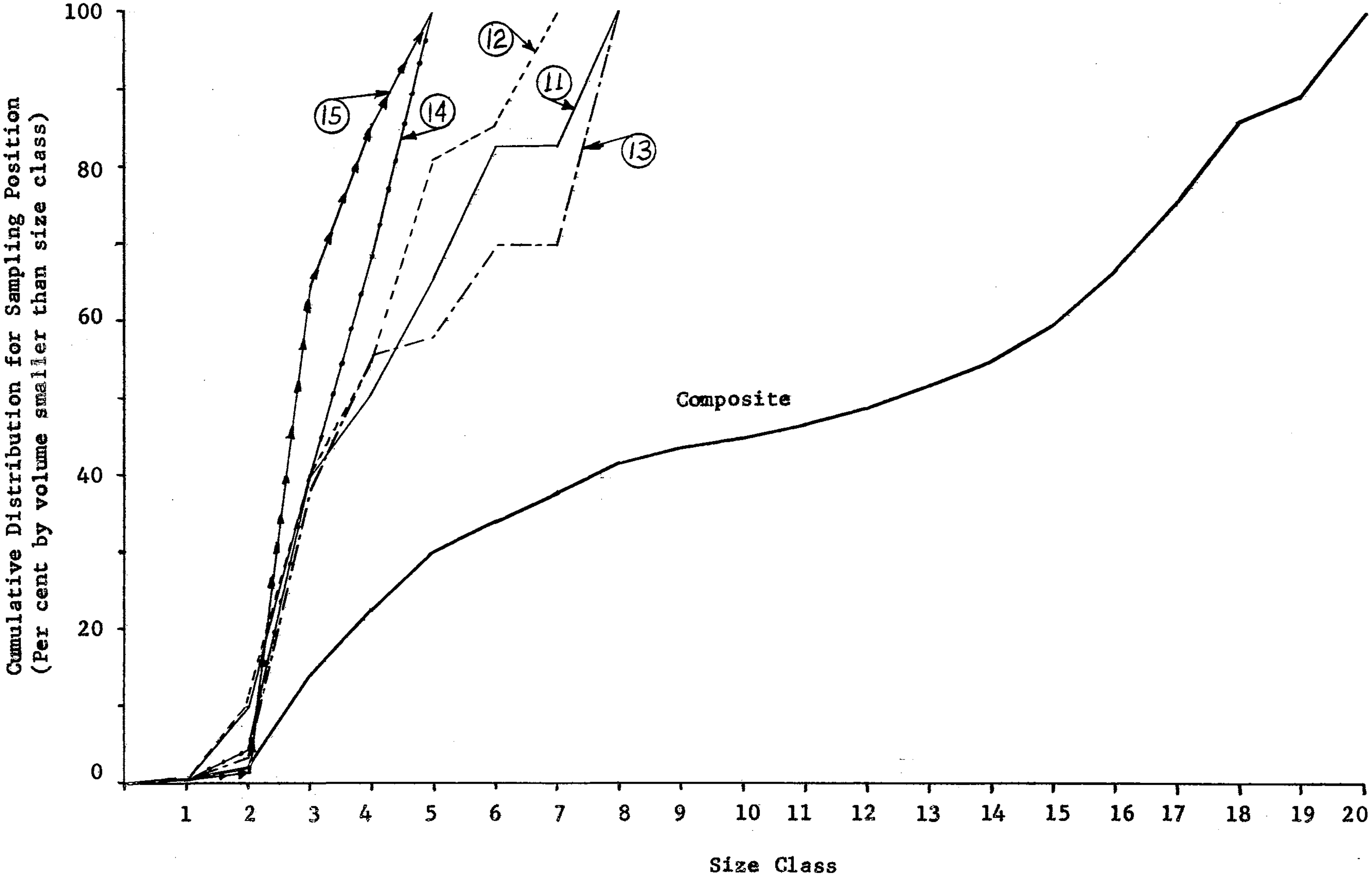


Fig. 22. Cumulative Volume Distributions (Positions 11-15) for Diesel Fuel at 20 psi.

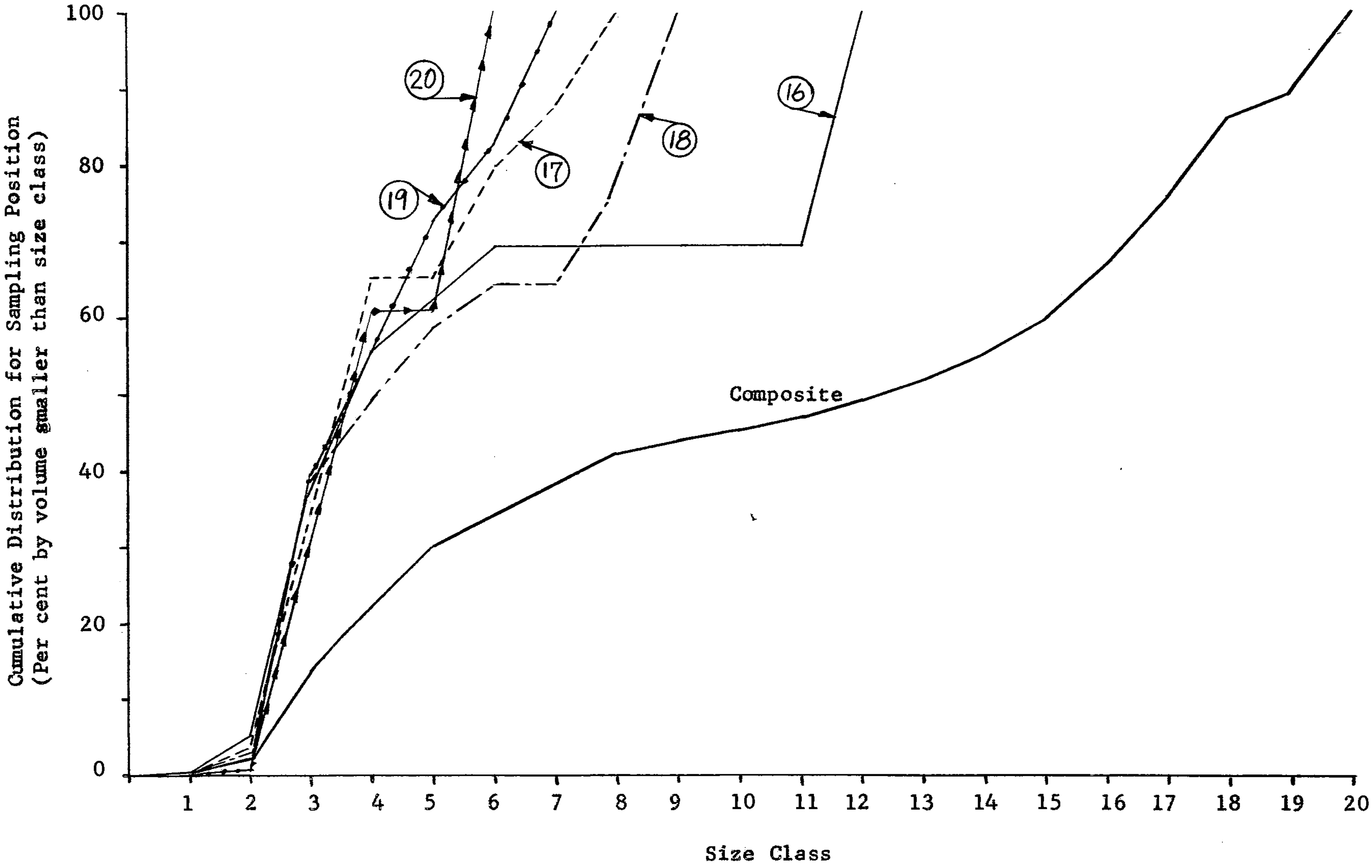


Fig. 23. Cumulative Volume Distributions (Positions 16-20) for Diesel Fuel at 20 psi.

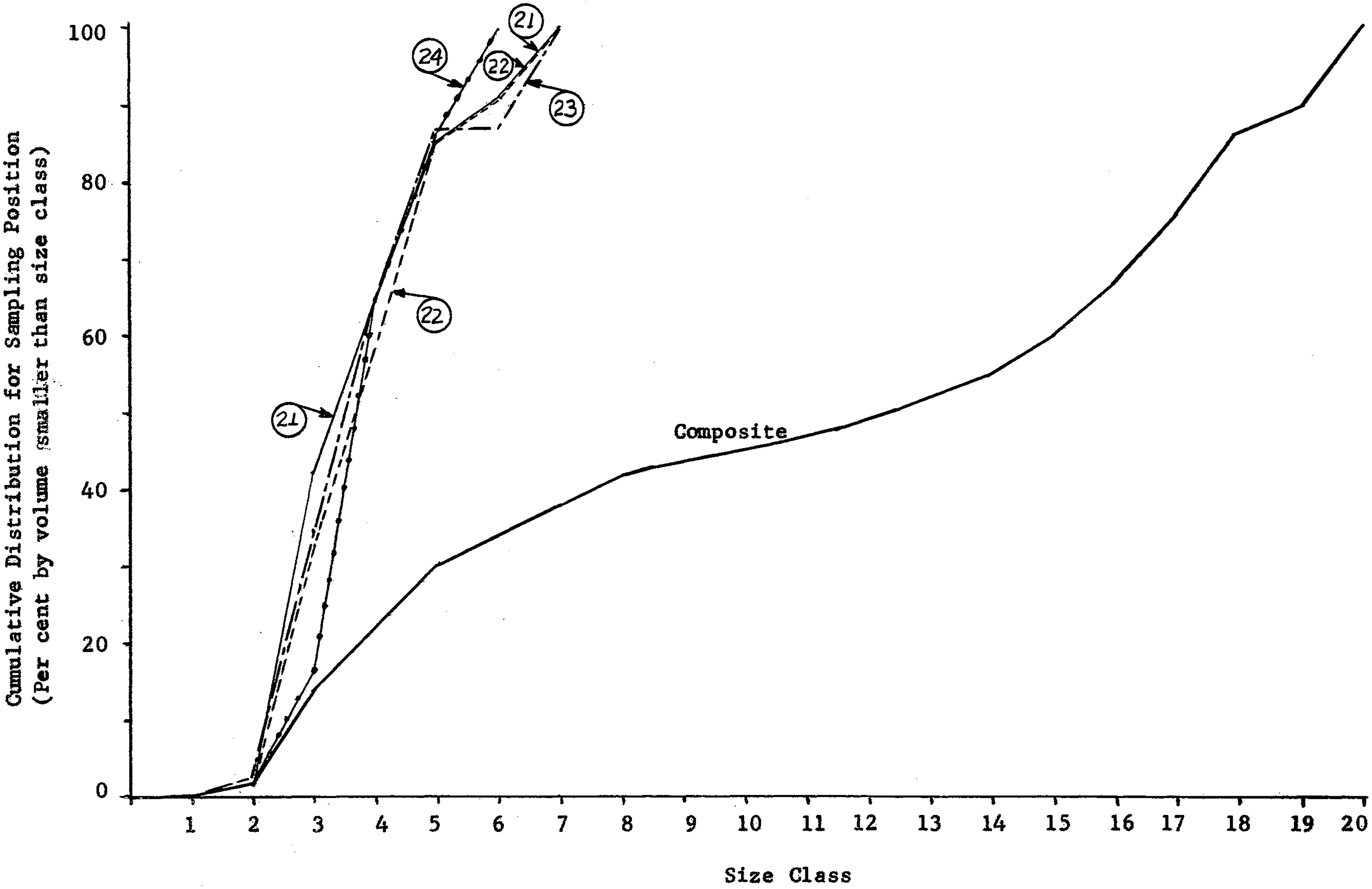


Fig. 24. Cumulative Volume Distributions (Positions 21-24) for Diesel Fuel at 20 psi.

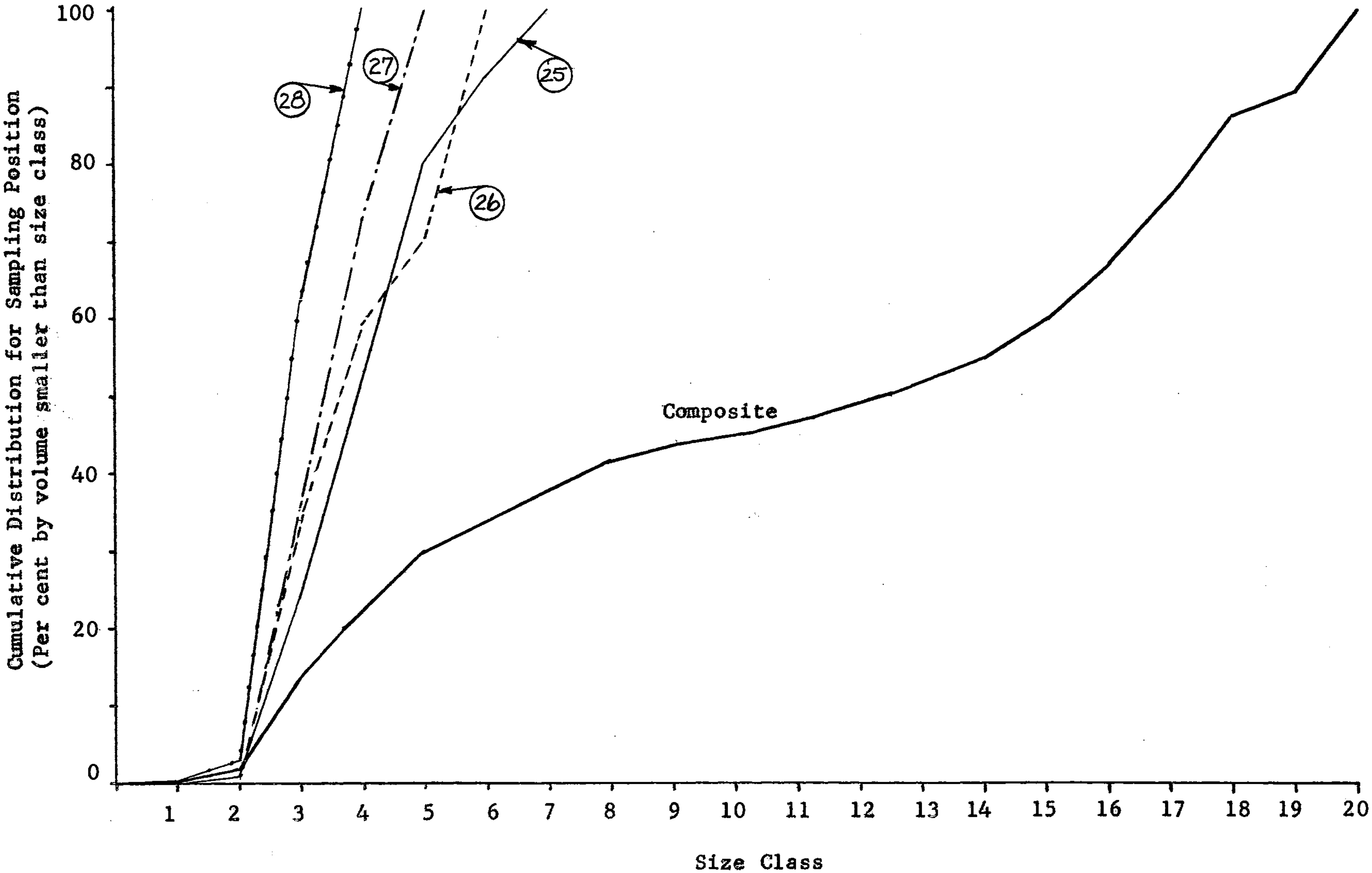


Fig. 25. Cumulative Volume Distributions (Positions 25-28) for Diesel Fuel at 20 psi.

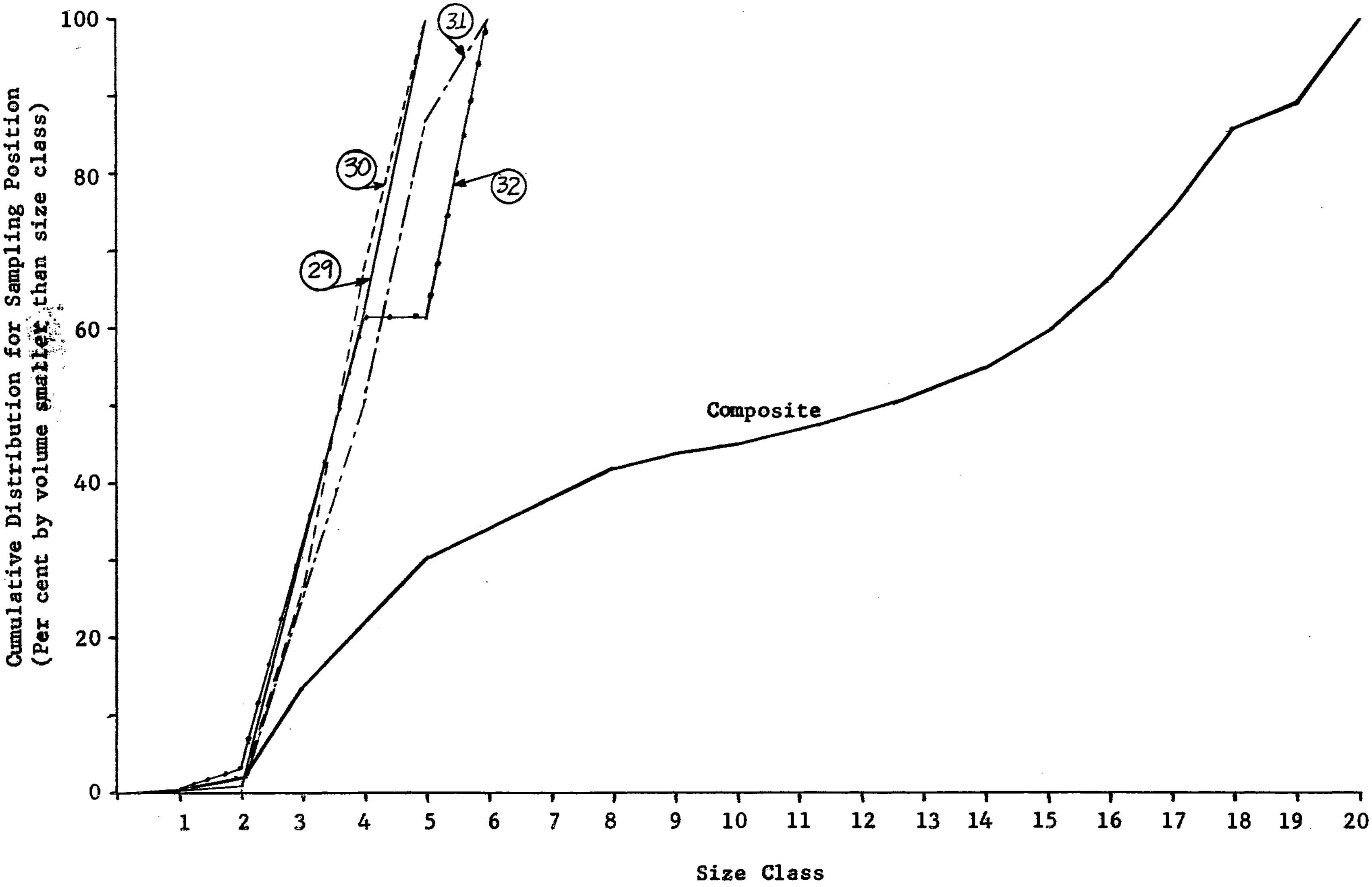


Fig. 26. Cumulative Volume Distributions (Positions 29-32) for Diesel Fuel at 20 psi.

TABLE VIII

VOLUME MEAN DROP DIAMETERS FOR EACH SAMPLING POSITION - WATER AT 40 PSI
MEAN DIAMETERS IN MICRONS

Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.
1	84.9	8	80.2	15	77.0	22	95.1	28	161.6
2	69.5	9	76.5	16	71.9	23	71.0	29	75.8
3	81.4	10	87.2	17	78.1	24	100.8	30	89.6
4	87.0	11	87.9	18	102.9	25	117.0	31	146.7
5	83.3	12	99.5	19	102.7	26	109.5	32	82.0
6	104.5	13	114.9	20	103.5	27	94.4		
7	115.5	14	117.2	21	64.5				

TABLE IX

VOLUME MEAN DROP DIAMETERS FOR EACH SAMPLING POSITION - DIESEL FUEL AT 20 PSI
MEAN DIAMETERS IN MICRONS

Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.	Samp. Pos.	Mean Dia.
1	68.2	6	79.4	11	59.2	16	68.7	21	70.1	25	81.4	29	71.8
2	59.9	7	60.5	12	60.5	17	64.4	22	75.2	26	74.0	30	74.0
3	73.7	8	67.6	13	70.6	18	73.7	23	71.7	27	71.2	31	74.9
4	225.1	9	77.9	14	65.9	19	74.8	24	74.5	28	61.4	32	67.5
5	67.1	10	67.8	15	60.4	20	70.8						

Variation in the distributions from point to point in the water spray appeared to be greater than that for the diesel fuel spray. This was apparently due to the increased liquid velocity and turbulence which caused the water to atomize and disperse in a more unpredictable manner.

Little or no treatment was given to other types of distributions (length, surface, surface-length, surface-volume, etc.) in this analysis, although for certain applications one or more of these might be appropriate.

An analysis was made of the volume distribution data to locate sampling positions in the fan spray pattern that would produce distributions similar to that of the entire spray.

The composite cumulative volume distributions shown in Table VII were compared with the cumulative volume distributions at each sampling position. For each sampling position a linear regression was made (composite cumulative distribution as the independent variable) to determine the regression coefficient (slope) of a least squares straight line that passed through the origin. The regression coefficient for this special case was calculated by:

$$b = \frac{\Sigma XY}{\Sigma X^2}$$

where:

b = regression coefficient

X = independent variable (composite cumulative distribution)

Y = dependent variable (cumulative distribution for given sampling position)

For each sampling position a correlation coefficient was also calculated to indicate the perfection with which the particular straight line represented the data:

$$r = \sqrt{\frac{(\leq XY)^2}{(\leq X^2)(Y^2)}}$$

where:

r = correlation coefficient

X = independent variable

Y = dependent variable

The regression and correlation coefficients for both test conditions are presented in Table X. A sampling position that was highly representative of the composite distribution had a regression coefficient of 1.0 and a correlation coefficient of 1.0. From Table X, sampling positions for both test conditions were selected where the regression coefficients and the correlation coefficients were very nearly 1.0. These most desirable sampling locations for the water data were positions 4, 6, 8, 11 or 13. For the diesel fuel data, positions 1, 3, 4 or 6 were the most desirable. For both test conditions, these most desirable sampling areas occurred in approximately the same positions in the fan spray pattern and were located at or near the sampling positions where the relatively large drops were found. Samples taken at these positions would provide the best representation of the composite distribution for the entire fan spray pattern.

TABLE X

REGRESSION AND CORRELATION COEFFICIENTS FOR FAN SPRAY DATA

Sampling Position	Water at 40 psi b	Water at 40 psi r	Diesel Fuel at 20 psi b	Diesel Fuel at 20 psi r
1	.811	.982	1.791	.989
2	1.570	.998	2.284	.989
3	1.018	.995	1.818	.983
4	1.000	.993	.592	.860
5	1.213	.991	2.917	.999
6	.966	.994	1.656	.987
7	.783	.970	2.232	.997
8	.979	.991	2.224	.998
9	1.256	.994	2.194	.995
10	1.242	.992	3.320	.998
11	1.071	.985	2.302	.997
12	.658	.955	2.585	.998
13	1.099	.969	2.126	.992
14	.751	.948	3.149	.997
15	1.883	.998	3.607	.992
16	1.828	.999	1.781	.988
17	2.239	.993	2.358	.997
18	.741	.968	1.982	.992
19	.990	.961	2.503	.998
20	1.354	.976	2.246	.985
21	3.214	.976	2.716	.998
22	1.278	.957	2.650	.998
23	1.363	.976	2.673	.998
24	.858	.978	2.758	.987
25	.760	.957	2.563	.996
26	1.128	.974	2.630	.994
27	1.522	.962	3.189	.995
28	.514	.813	4.408	.998
29	1.993	.984	3.003	.991
30	1.448	.968	3.040	.988
31	.601	.883	2.685	.990
32	1.800	.946	2.545	.988

Analysis of the Replication Selection Procedure

The sampling pattern data obtained from the fan nozzle, based on the number of sample replications previously determined, was analyzed to ascertain the validity of the replication selection procedure and to examine the variation of the standard deviations in the mean drop sizes from point to point in the spray pattern.

The volume mean drop diameter was calculated for each replication and each sampling position. The standard deviation for the replication volume mean diameters was then calculated for each sampling position. Assuming an allowable error in the sample mean of ±12 microns, the number of replications required at each sampling position was then determined. The results are summarized in Tables XI and XII.

The number of replications selected for sampling the water spray at 40 psi was probably inadequate based on the results in Table XI. The average standard deviation of the mean drop diameters for all the sampling positions was about three times the standard deviation of the mean drop diameters for the single sampling position upon which the replication number was based. The standard deviation varied widely in magnitude for the different sampling positions. However, the large variations in the standard deviation occurred in those sampling positions where either a few extremely large drops were found or where drop concentration (drops per sample) was very small. The standard deviations for the 25 sampling positions where

TABLE XI

VOLUME MEAN DIAMETERS AND STANDARD DEVIATIONS FOR SAMPLE REPLICATION DATA

WATER AT 40 PSI

Samp. Pos.	Volume Mean Diameter (Microns)					Std. Dev.	No. of Samp. for L = 12
	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Ave.		
1	109.0	80.9	53.3	55.9	74.8	26.0	18.7
2	78.5	51.6	81.6	37.4	62.3	21.3	12.6
3	90.1	55.1	54.8	118.2	79.5	30.6	26.0
4	75.9	114.8	69.2	61.5	80.4	23.7	15.6
5	64.1	110.9	72.7	96.5	86.0	21.5	12.8
6	98.6	114.3	83.0	107.5	100.9	13.5	5.0
7	140.2	84.2	92.8	153.6	117.7	34.3	32.8
8	68.9	62.5	188.5	87.6	101.9	58.6	95.7
9	70.1	88.9	71.4	75.5	76.5	8.6	2.0
10	93.4	95.2	70.1	73.3	83.0	13.1	4.7
11	73.4	93.1	49.2	113.3	82.2	27.3	20.7
12	67.2	144.4	85.3	51.9	87.2	40.5	45.6
13	104.2	126.3	116.0	124.9	117.9	10.1	2.8
14	107.0	92.8	108.1	152.4	115.1	25.8	18.5
15	69.6	80.9	72.6	84.8	77.0	7.1	1.4
16	83.9	64.5	78.1	61.9	72.1	10.6	3.1
17	85.9	74.2	68.9	72.8	75.4	7.3	1.4
18	136.1	65.5	48.3	66.5	79.1	38.9	42.0
19	118.1	.0	97.6	89.2	76.2	52.2	75.9
20	103.9	109.8	.0	97.2	77.7	52.1	75.4
21	30.1	.0	71.2	80.8	45.5	37.4	39.0
22	93.1	85.1	101.5	137.4	104.3	23.0	14.8
23	65.5	87.4	43.0	106.9	75.7	27.6	21.1
24	73.1	77.0	140.6	68.7	89.8	34.0	32.1
25	81.5	237.4	97.2	112.4	132.2	71.3	141.2
26	98.2	101.5	140.1	86.4	106.5	23.2	15.0
27	94.2	71.2	112.4	101.5	94.8	17.4	8.4
28	175.5	.0	87.4	.0	65.7	84.0	196.1
29	71.6	112.4	52.9	77.7	78.7	24.8	17.1
30	63.6	112.4	74.8	112.4	90.8	25.3	17.8
31	37.4	.0	.0	167.6	51.2	79.5	175.7
32	37.4	112.4	88.7	52.9	72.9	34.0	32.1

TABLE XII

VOLUME MEAN DIAMETERS AND STANDARD DEVIATIONS FOR SAMPLE REPLICATION DATA

DIESEL FUEL AT 20 PSI

Samp.	Volume Mean Diameter (Microns)					Std.	No. of Samp. for
Pos.	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Ave.	Dev.	L = 12
1	70.0	66.2	65.3	72.1	68.4	3.2	.2
2	51.2	50.2	85.1	68.6	63.8	16.5	7.5
3	83.0	54.5	74.4	67.5	69.8	12.0	4.0
4	189.5	237.2	258.5	267.5	238.2	34.8	33.7
5	74.0	52.2	57.2	76.0	64.8	11.9	3.9
6	78.9	65.7	68.3	113.1	81.5	21.8	13.2
7	55.5	48.7	75.1	70.8	62.5	12.4	4.3
8	66.7	45.3	80.2	53.8	61.5	15.2	6.4
9	81.0	58.4	83.1	54.1	69.1	15.0	6.2
10	71.2	62.5	70.9	58.1	65.7	6.4	1.1
11	48.8	57.3	69.1	65.3	60.1	8.9	2.2
12	62.4	50.7	62.8	66.9	60.7	6.9	1.3
13	72.8	80.7	76.1	47.9	69.4	14.6	6.0
14	67.6	54.2	77.2	53.9	63.2	11.2	3.5
15	63.1	61.7	56.0	56.6	59.4	3.5	.3
16	66.0	49.2	80.0	61.0	64.0	12.7	4.5
17	64.5	68.8	56.0	67.5	64.2	5.7	.9
18	64.5	79.8	81.1	69.8	73.8	7.9	1.7
19	74.8	94.5	61.1	67.0	74.3	14.5	5.8
20	90.5	50.6	68.0	69.0	69.5	16.3	7.4
21	73.7	72.4	65.4	63.2	68.7	5.1	.7
22	77.6	57.3	88.8	71.0	73.7	13.1	4.8
23	77.3	64.8	73.2	63.8	69.8	6.5	1.1
24	69.0	84.0	88.2	61.2	75.6	12.6	4.4
25	73.8	94.6	84.8	93.2	86.6	9.5	2.5
26	75.5	64.8	74.9	74.0	72.3	5.0	.7
27	73.7	67.6	67.7	75.5	71.1	4.0	.4
28	62.9	62.4	67.3	43.5	59.0	10.5	3.0
29	71.0	86.5	70.7	12.4	60.2	32.6	29.6
30	78.6	72.8	76.9	55.9	71.0	10.3	2.9
31	79.0	61.5	83.9	61.6	71.5	11.6	3.7
32	81.0	53.3	76.4	62.4	68.3	12.7	4.5

the previously mentioned conditions did not exist were considered to have sufficient uniformity to justify the original assumption.

The number of replications selected for sampling the diesel fuel spray at 20 psi appeared satisfactory as shown in Table XII. The average standard deviation of the mean drop diameters for all sampling positions was about the same as for the single sampling position. Further, with few exceptions, the standard deviation was relatively invariant for the different sampling positions. As with the water spray data, in positions where either extremely large drops were found or where the drop concentration was small, the standard deviation became rather large.

Electrostatic Dispersion of Laminar Flow Jet Streams

The atomization characteristics of the laminar flow jets with and without voltage applied to a tube surrounding the jet streams are summarized in Tables XIII, XIV, XV and XVI. The original data for this section may be found in Appendix B. Since the effect of the charged collector tube on the large drop size and uniformity was of particular interest, the sample mean large drop diameters for both test conditions were compared using a two group analysis. The statistical calculations are presented in Tables XVII and XVIII.

No significant difference was found between the means of the large drops from the Delavan CS-1 orifice for the two treatments. It should be noted, however, that considerable difference is shown in the group variances. This would suggest that the size uniformity of

TABLE XIII

SPRAY CHARACTERISTICS FOR DELAVAN CS-1 ORIFICE
NO VOLTAGE

Neg. No.	Ave. Drop Dia. (Microns) Large	Small	No. Drops Per Samp. Large	Small	Vol. Fr.*	No. Fr.**
19	515.5		11	0	1.000	1.000
20	523.4	18.7	9	1	.999	.888
21	562.2		9	0	1.000	1.000
22	518.6	19.9	11	1	.999	.916
23	555.2		9	0	1.000	1.000
24	563.3	14.9	9	2	.999	.818
25	544.2		12	0	1.000	1.000
26	579.5	18.7	9	1	.999	.900
27	537.2		10	0	1.000	1.000
28	531.7		10	1	1.000	1.000
32	531.2	16.2	11	1	.999	.916
29	524.0		10	0	1.000	1.000
30	561.5		9	0	1.000	1.000
31	534.0		11	0	1.000	1.000
33	566.2	16.2	9	1	.999	.900
34	532.1	21.2	11	1	.999	.923
35	538.4		10	0	1.000	1.000
36	507.2		11	0	1.000	1.000
Average	540.3	17.6	10	0.5	.999	.957

* Volume Fraction = $\frac{\text{Volume of Large Drops}}{\text{Total Volume of Large and Small Drops}}$

** Number Fraction = $\frac{\text{Number of Large Drops}}{\text{Total Number of Large and Small Drops}}$

TABLE XIV

SPRAY CHARACTERISTICS FOR DELAVAN CS-1 ORIFICE ONE KILOVOLT POTENTIAL ON TUBE

Negative Number	Ave. Drop Dia. (Microns) Large	Small*	No. Drops Per Sample Large	Small
19	517.2		11	0
20	527.3		9	0
21	484.2		10	0
22	555.4		9	0
24	511.0		10	0
25	606.1		6	0
26	522.9		10	0
27	499.6		11	0
28	576.4		8	0
29	509.9		10	0
30	538.4		11	0
31	548.0		8	0
32	535.5		9	0
33	540.4		8	0
34	539.7		8	0
35	538.4		8	0
36	570.7		9	0
Average	536.5		9.1	0

* No small drops were found on the negatives

TABLE XV

SPRAY CHARACTERISTICS FOR SPRAYING SYSTEMS X-1 ORIFICE
NO VOLTAGE

Neg. No.	Ave. Drop Dia. (Microns) Large	Small	No. Drops Per Samp. Large	Small	Vol. Fr.*	No. Fr.**
1	1138.8	249.9	4.	1.	.997	.800
2	1100.1	306.2	5	2	.991	.714
3	964.4	17.4	5	3	.999	.625
4	1044.2	299.9	5	2	.989	.714
5	1109.9	21.2	4	4	.999	.500
6	1218.4	337.2	3	2	.986	.600
7	1136.3	287.4	4	1	.996	.800
8	1127.2	159.3	4	2	.995	.666
9	1114.6	299.9	4	1	.995	.800
10	1167.8	233.3	4	3	.991	.571
18	1124.0	249.9	6	1	.998	.857
11	1125.4	299.5	5	3	.988	.625
12	1151.1	249.9	5	1	.998	.833
13	1110.6	236.6	3	3	.980	.500
14	1216.5	159.9	3	2	.995	.600
15	1064.7	287.4	4	1	.995	.800
16	1069.3	320.7	5	1	.994	.833
17	1019.4	312.4	5	1	.994	.833
Average	1111.3	212.6	4.3	1.9	.993	.696

$$* \text{ Volume Fraction} = \frac{\text{Volume of Large Drops}}{\text{Total Volume of Large and Small Drops}}$$

$$** \text{ Number Fraction} = \frac{\text{Number of Large Drops}}{\text{Total Number of Large and Small Drops}}$$

TABLE XVI

SPRAY CHARACTERISTICS FOR SPRAYING SYSTEMS X-1 ORIFICE TWO KILOVOLTS POTENTIAL ON TUBE

Negative Number	Ave. Drop Dia. (Microns) Large	Ave. Drop Dia. (Microns) Small *	No. Drops Per Sample Large	No. Drops Per Sample Small
1	1052.3		6	0
2	1148.8		4	0
3	1038.8		5	0
4	1181.7		4	0
5	1048.5		6	0
6	1041.4		5	0
7	1058.9		6	0
8	1063.2		5	0
9	1061.1		6	0
10	1076.5		4	0
11	1069.1		5	0
12	1056.4		5	0
13	1157.3		5	0
14	1056.1		6	0
15	1039.3		5	0
16	1058.2		5	0
17	924.1		5	0
18	1011.4		5	0
Average	1063.5		5.1	0

* No small drops were found on the negatives

TABLE XVII

ANALYSIS OF DELAVAN CS-1 LAMINAR FLOW JET DATA AS TWO RANDOMIZED GROUPS

Treatment	d. f.	Mean Drop Dia. (Microns)	SS	Variance
1 Kilovolt	16	536.5	14,214.4	888.4
No Voltage	17	540.3	6,907.1	406.3

$t_{calc} = 0.44$

$t_{05}^{33} = 2.03$

TABLE XVIII

ANALYSIS OF SPRAYING SYSTEMS X-1 LAMINAR FLOW JET DATA AS TWO RANDOMIZED GROUPS

Treatment	d. f.	Mean Drop Dia. (Microns)	SS	Variance
2 Kilovolts	17	1063.5	54,595.5	3211.5
No Voltage	17	1111.3	67,896.3	3993.9

$t_{calc} = 2.39$

$t_{05}^{34} = 2.03$

the charged drops was less than that of the uncharged drops.

The group large drop diameter means from the Spraying Systems X-1 orifice were considered to be different for the probability (95%) selected. In this instance, the drops produced in the charged stream were smaller and, judging from the variance, were more uniform in size than their counterparts in the uncharged stream.

These data would appear somewhat conflicting, and are, in part, contrary to preliminary observations of the phenomenon. The exact effects of a charged field on the atomization process are not known. However, the general effect of an induced charge on the surface of a liquid would be to cause forces (repulsion between charges on the liquid surface) opposing liquid surface tension. The smaller diameter liquid column emerging from the Delavan CS-1 orifice and the resulting relatively small drops (small mass and surface area) would likely be affected by the electrical charges to a greater degree than the rather large liquid column and drops formed from the larger orifice.

Representative samples of the charged and uncharged drops are shown in Figs. 27, 28, 29, and 30. The charged drops (Figs. 28 and 30) have dispersed to a much greater degree than their uncharged counterparts (Figs. 27 and 29) and would appear to be more uniform in size and shape. At this sampling distance the larger drops had not yet had time to become shape stabilized. However, at larger distances greater dispersion would have caused some of the drops to pass out of the field of focus before sampling.

Inspection of the Delavan CS-1 data shows about one drop less

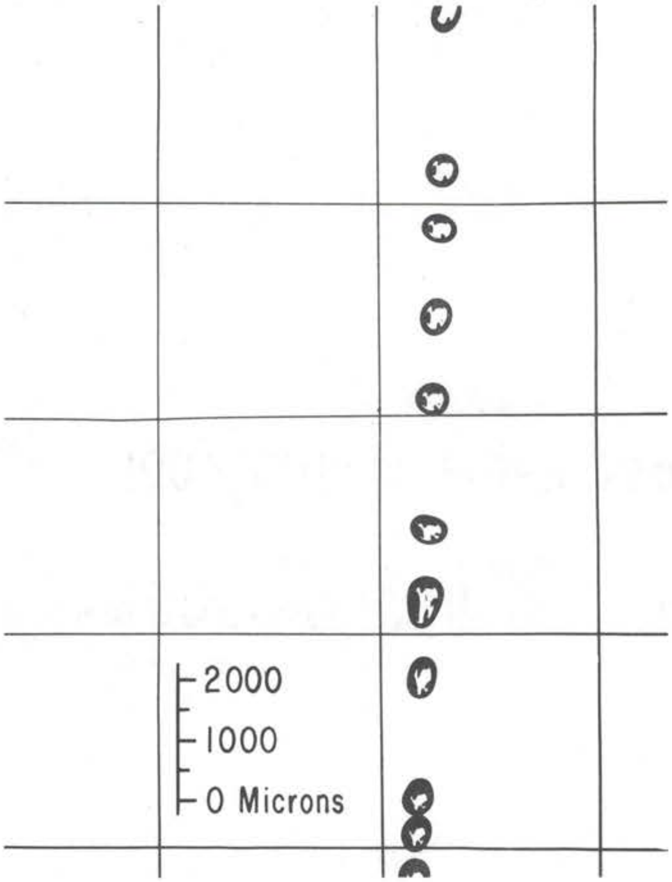


Fig. 27. Uncharged Jet Stream Breakup, Delavan CS-1 at 3 psi.

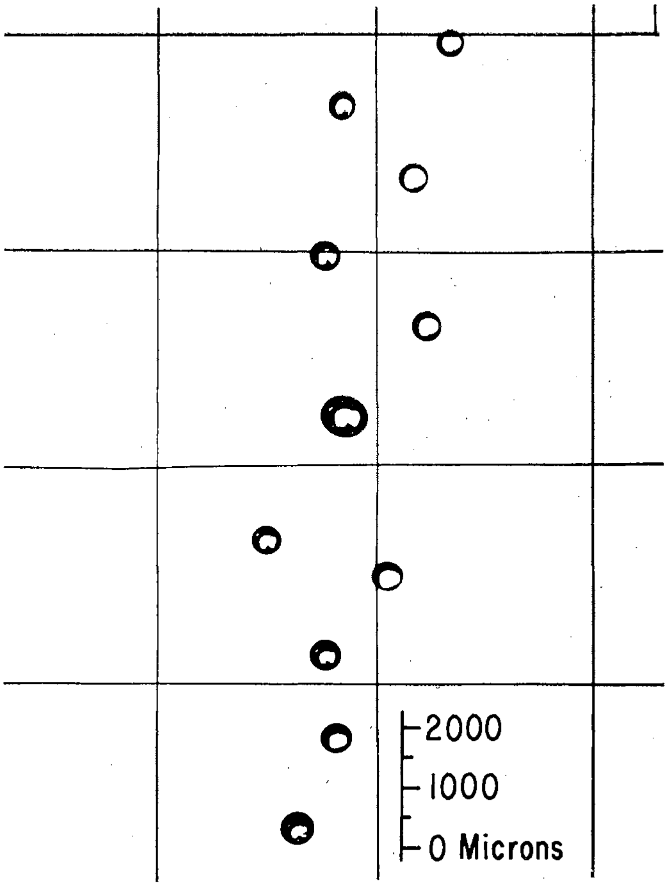


Fig. 28. Dispersion of Jet Stream from Delavan CS-1 Orifice at 3 psi with One Kilovolt Potential on Tube.

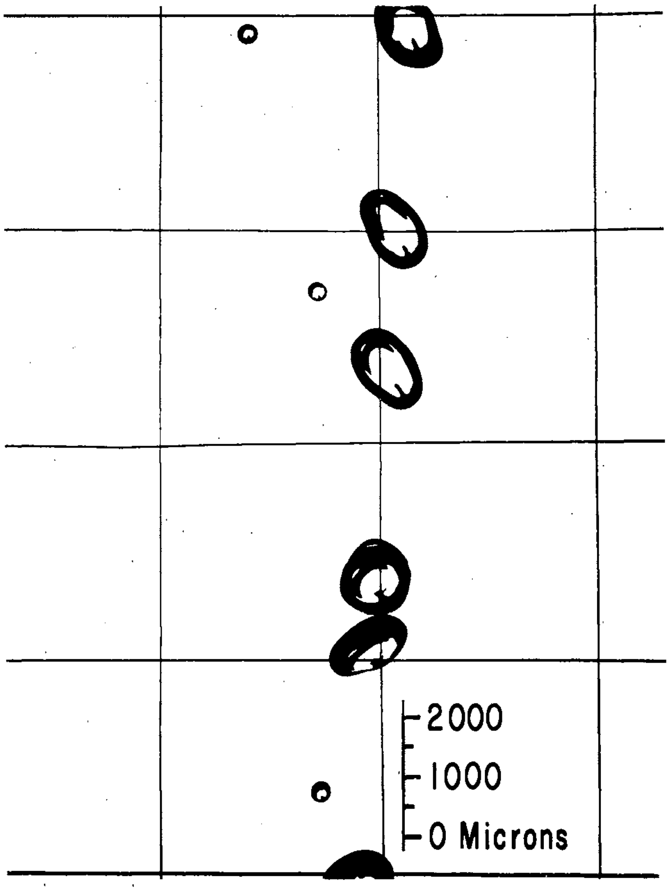


Fig. 29. Uncharged Jet Stream Breakup, Spraying Systems X-1 at 1 psi.

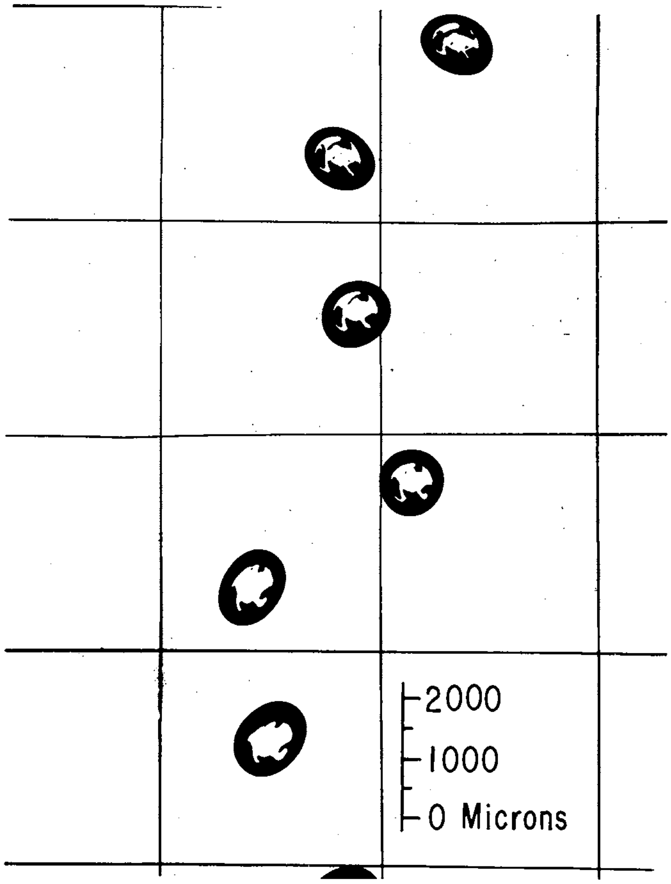


Fig. 30. Dispersion of Jet Stream from Spraying Systems X-1 Orifice at 1 psi with Two Kilovolts Potential on Tube.

per sample in the charged stream. Since the orifice flow rate and drop sizes were essentially unchanged for both test conditions, it is suggested that the induced charge created sufficient dispersion within the tube to cause an occasional large drop (smaller than average size) to impact on the inner surface of the collector tube. The Spraying Systems X-1 data shows an increase of about one drop per sample in the charged stream compared with the uncharged stream. However, to maintain the same flow rate, more smaller drops would need to be present.

The drop collection data is summarized in Table XIX. No small drops were found in any of the samples when the collector tube was charged. Thus, for the condition of the test, the charged collector tube was extremely effective in eliminating the small drop component from the spray. The amount of liquid collected from the tube corresponds closely with the relative small drop volume found in the uncharged streams. For the Delavan CS-1 orifice, the (large) drops passing out of the charged collector tube represented 99.17 per cent of the total volume collected whereas in the uncharged stream the large drops represented 99.9 per cent of the total volume. Similar results were obtained from the Spraying Systems X-1 orifice with the charged tube collecting 1.04 per cent of the liquid discharged by the orifice. The small drop component of the uncharged stream was 0.70 per cent of the total volume. For both orifices, some liquid in excess of the volume represented by the small drops was apparently collected on the inside of the charged tube.

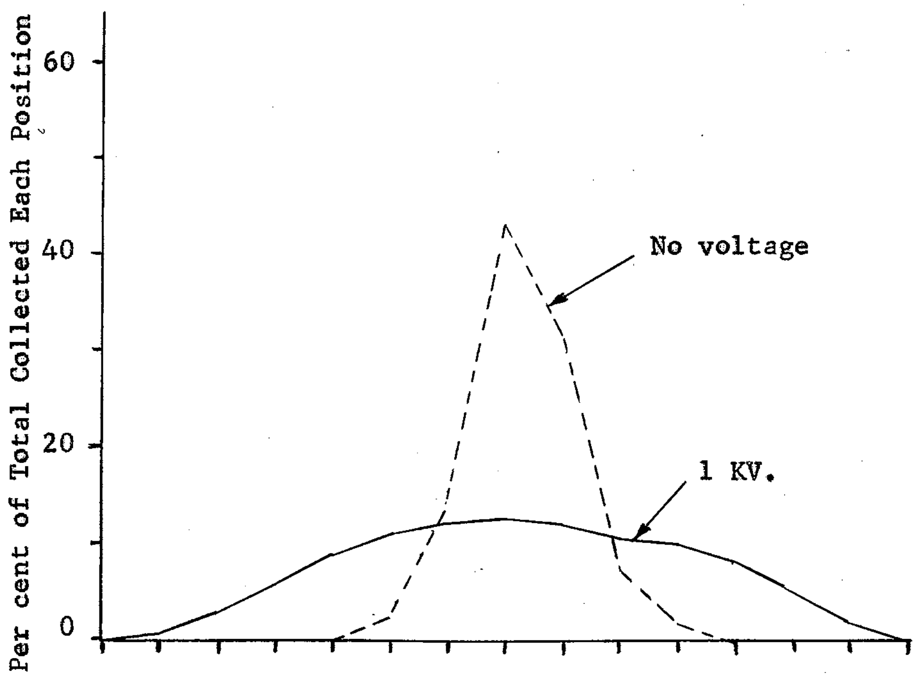
TABLE XIX

DROP COLLECTION ON CHARGED TUBE SURROUNDING LAMINAR FLOW JET STREAM

Orifice	Psi	Liquid Collected in Charged Tube (% by wt)	Orifice Flow Rate (gal/hr)
Delavan CS-1	3	0.83	0.290
Spraying Systems X-1	1	1.04	0.693

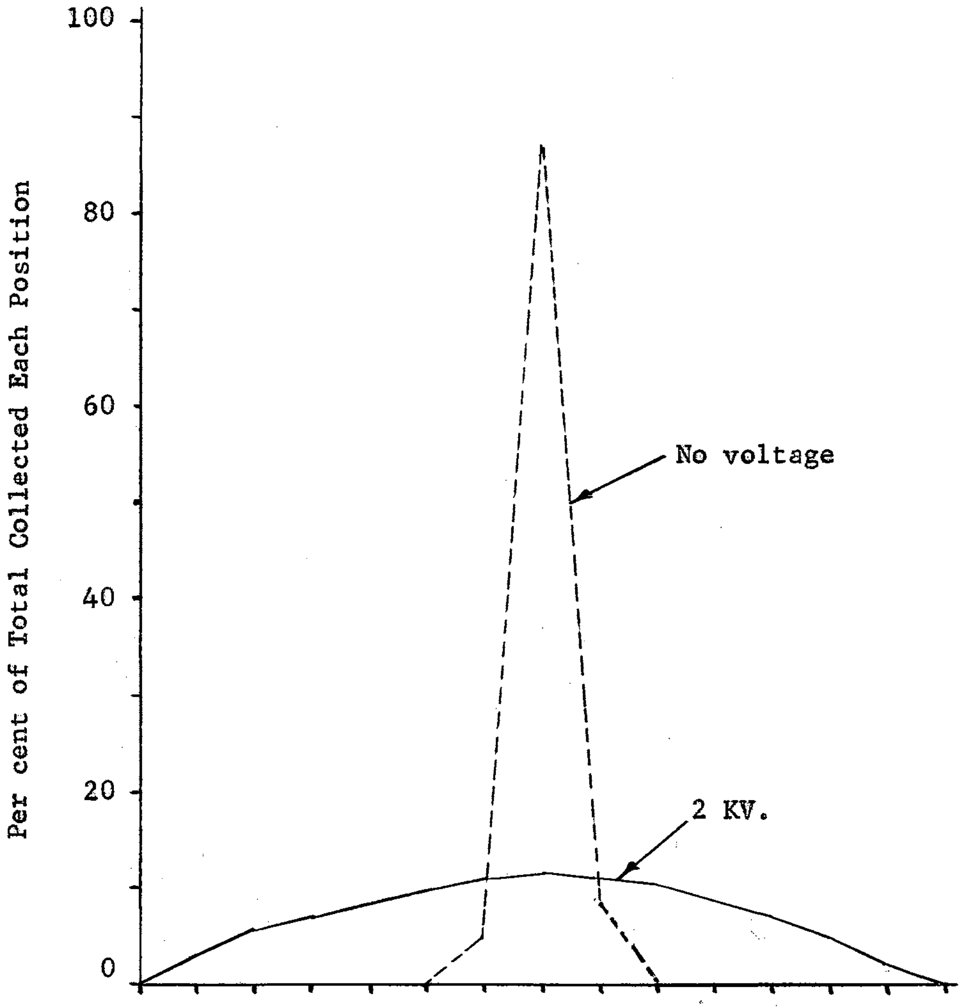
The lateral spray dispersion patterns for the charged and uncharged horizontal laminar flow jet streams are shown in Figs. 31 and 32. Charging of the streams caused considerable lateral dispersion of the drops. The uncharged Delavan jet stream deposited 74 per cent of the spray in a band two inches wide while the charged stream resulted in 84 per cent being deposited over an eight inch width. The uncharged Spraying Systems jet stream deposited 86.9 per cent of the spray in a one inch width. When the stream was charged, 77.4 per cent was deposited in an eight inch band. Thus, charging of the jet streams caused dispersion that would allow an increase in nozzle spacing from two to four times while maintaining a relatively uniform application from side to side across the pattern.

The changes in the size of the dispersion pattern of the charged and uncharged jet streams in the direction of the jet streams are shown graphically in Figs. 33 and 34. Although no measure was made



Catchment Channel Collection Tube Position
(One Inch Spacing)

Fig. 31. Dispersion Pattern for Charged and Uncharged Horizontal Laminar Flow Jet 24 Inches Above Catchment Channels - Delavan CS-1 at 3 psi.



Catchment Channel Collection Tube Position
(One Inch Spacing)

Fig. 32. Dispersion Pattern for Charged and Uncharged Horizontal Laminar Flow Jet 24 Inches Above Catchment Channels - Spraying Systems X-1 at 1 psi.

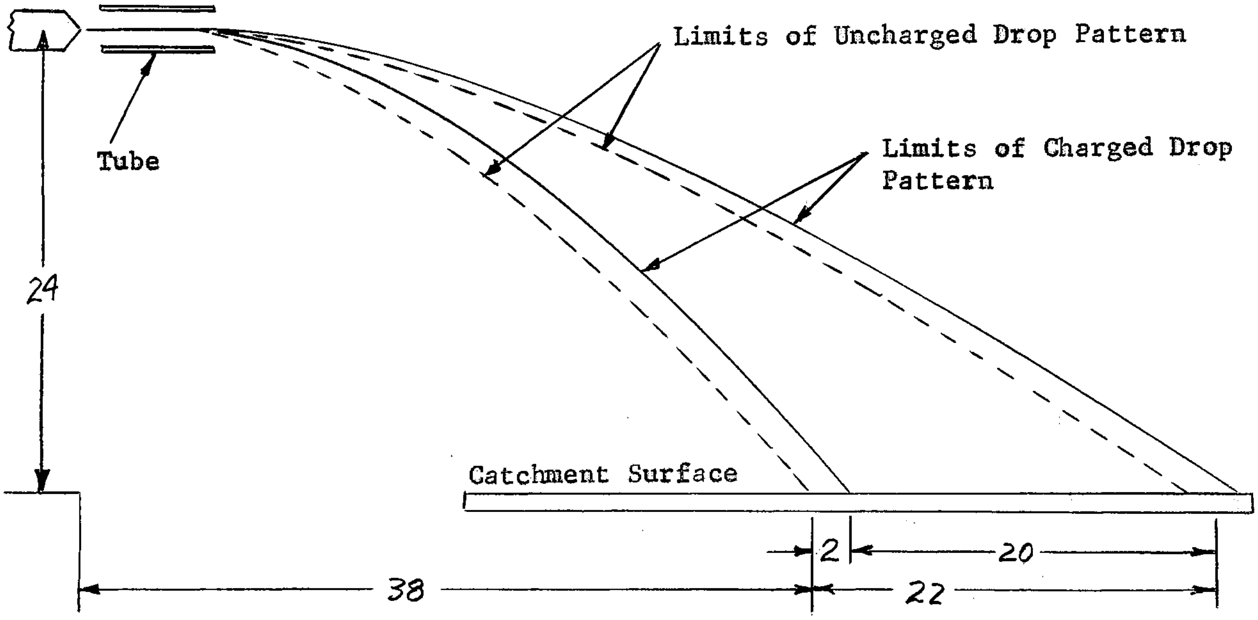


Fig. 33. Dimensions of the Dispersion Pattern Parallel to Jet Axis for Delavan CS-1 at 3 psi.

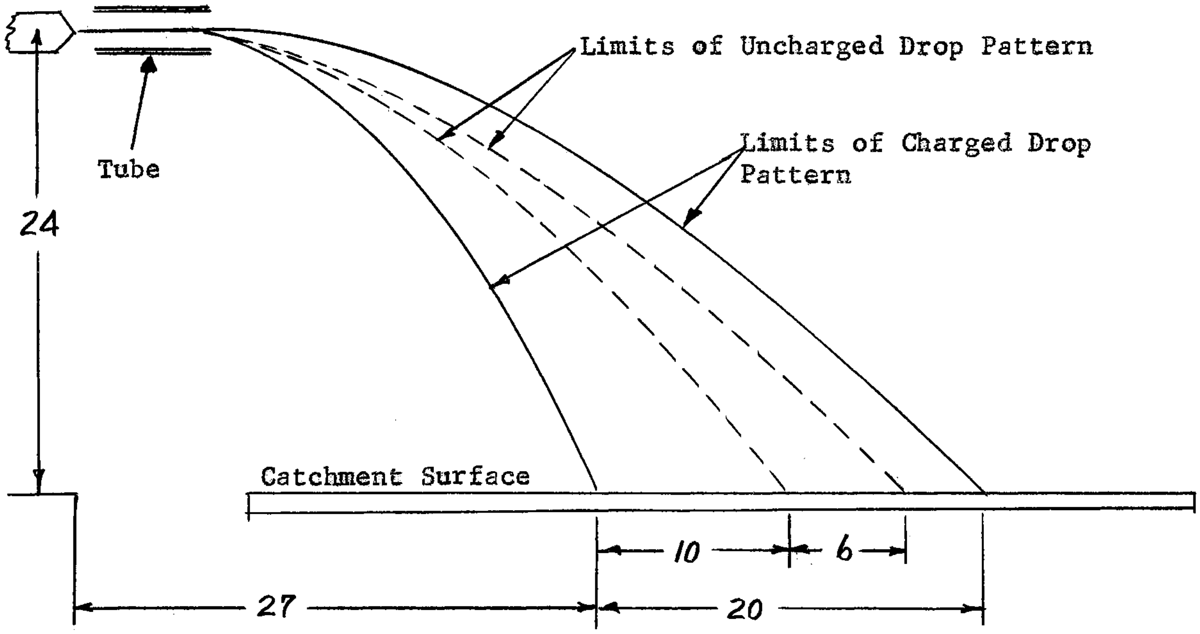


Fig. 34. Dimensions of the Dispersion Pattern Parallel to Jet Axis for Spraying Systems X-1 at 1 psi.

of the volume distribution in this direction, the figures do show an increase in the pattern size for the charged streams.

Stroboscopic examination of the charged jet streams in a darkened room showed that all of the drops emerging from the charged tube impacted on the catchment surface. Drops were also observed to continue impacting on the surface without observable deflection (due to mutual drop-catchment surface repulsion) even after long periods of operation with the catchment surface well insulated from ground. Thus, any charge buildup on the catchment surface was not a deterrent to drop impaction.

With the equipment used, no current flow was recorded for either the one kilovolt or the two kilovolt potentials on the charged tube. The DC power supply used was equipped with a microammeter having one scale range of 0-10 microamperes. For the test voltages, the meter needle would move between zero and one microampere.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

The objectives of this study were to: (1) develop an apparatus and techniques to quantitatively measure the size distributions of particles formed in liquid atomization, (2) determine and characterize the particle size distribution of sprays for improvement in sampling procedures and (3) refine a method of atomization that would produce spray containing a narrow size range of particles of a predictable size.

A photographic sampling apparatus was designed and developed that would provide in-flight samples (photographs) of spray drops at or near the zone of atomization. The equipment was especially designed to produce a minimum of disturbance to the spray before and during the sampling process. Illumination was provided in the form of high-speed high-intensity flash units to obtain effective camera magnifications of from 8-12 times and to permit controlled double exposure photography for spray drop velocity determinations. A number of photographic techniques were developed and employed that assisted in producing reliable high quality sample negatives.

Sampling techniques and procedures were developed to determine:

(1) where in a spray pattern sampling should occur to obtain samples representative of the entire spray and (2) how many samples (replications) would be necessary to establish a reasonable level of confidence in the results.

Test conditions were established using a conventional fan spray nozzle. A number of samples were taken at a single location in the spray pattern and were analyzed to provide an estimate of the sampling variance. This having been established, the number of sample replications to be made were then estimated.

Samples were also taken along a drop stream at intervals to arrive at a desired sampling distance from the atomizer. Based on the changes in drop velocities, drop configuration stability and drop dispersion, a desirable sampling distance was determined.

Spray from one quadrant of the fan nozzle was sampled in great detail to provide almost continuous information concerning the changes in drop size distributions from one part of the pattern to another. Analyses of these data provided an indication of potential sampling locations in a fan spray pattern where drop size distributions could be found that would be characteristic of the entire spray from the nozzle.

The sampling pattern data was further analyzed to ascertain the validity of the replication selection procedure. These results showed that for one test condition (water at 40 psi) the number of replications selected was probably not sufficient. The average standard deviation of the mean drop diameters for all sampling positions was found to be large as compared to the standard deviations of the mean drop diameters for the single sampling location upon which the number of replications were based. The number of replications selected for the other test condition, however, was considered satisfactory. For both test conditions, the standard deviations of the mean drop diameters were relatively invariant over most of the sampling locations which provided justification and support for the original assumption.

The atomization characteristics of a laminar flow jet stream with and without voltage applied to a cylindrical tube surrounding the jet stream were determined.

The laminar flow jet stream, without voltage applied to the tube, atomized predictably into relatively uniform large drops (approximately two times the diameter of the orifice) interspersed by occasional drops much smaller and more variable in diameter. The changes in the atomization caused by the charged tube surrounding the jet stream were measured in terms of drop size and uniformity. For one test condition, the charged drops were no different in size from the uncharged, but had less uniformity. For another test condition, where drops were larger, the charged drops were significantly smaller in size and possessed greater uniformity than uncharged drops.

The charged tube surrounding the jet stream was very effective in eliminating the small drop component of a laminar flow jet stream spray. Liquid collected on the inside of the charged tube represented approximately the same volume as the small drop fraction occurring in the uncharged jet breakup. No small drops were found in any of the samples where the tube was charged.

Measure was also made of the lateral dispersion of the charged drops due to drop mutual repulsion. An uncharged horizontal jet stream deposited 74 per cent of the spray in a two inch wide band. A similar charged stream resulted in 84 per cent being deposited over an eight inch width.

Conclusions

The sampling procedure for determining the drop size distributions in a fan spray can be greatly simplified using the equipment, techniques and procedures established in this study. The equipment, techniques and procedures were adapted and used for other atomizing conditions.

A charged tube surrounding a laminar flow jet stream was very effective in eliminating the small drop component of the jet stream breakup. Sufficient charge was induced on the drops to cause mutual repulsion and dispersion to an extent that the effective application width was increased by four times. Relatively small changes in individual drop characteristics were obtained by the induced charging of the jet stream under the test conditions established.

Suggestions for Future Investigations

Induced charging of spray drops opens a new area of investigation in controlled liquid atomization research. The work reported herein may be considered a first attempt to demonstrate the feasibility of such an approach. Several questions would seem worthwhile subjects for further study:

1. What would be an optimum charged surface configuration (shape, length, size, position, etc.) for effective charging of the stream and collection of small (driftable) drops.
2. Could the drops from non-laminar flow atomizers be charged and separated electrostatically?
3. How long does an induced particle charge persist? Could a charged spray drop be given sufficient charge that, upon approaching an oppositely charged object, electrostatic forces would predominate and result in impact of the drop on the object?
4. What liquid physical properties determine the extent to which a surface charge may be induced on a drop?

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APPENDIX A

DEPTH OF FIELD CALCULATIONS

VISCOSITY AND SURFACE TENSION OF LIQUIDS USED

APPENDIX A-I

DEPTH OF FIELD CALCULATIONS

The following depth of field calculations are based on a circle of confusion that is a fraction of the focal length of the lens. The blurred image circle that occurs when an object is located outside of the plane focused upon is known as the "circle of confusion". The farther the object is from the plane focused upon, the larger the circle of confusion. For critical definition, a common value of the diameter of the circle of confusion is 1/1720 of the focal length of the lens (or 2 minutes of arc in angular measure). The depth of field limits as measured from the lens may be calculated from the following formulas:

$$\text{Near limit} = O - \frac{O^2 \tan \theta}{L + O \tan \theta}$$

$$\text{Far limit} = O + \frac{O^2 \tan \theta}{L - O \tan \theta}$$

where O = the object distance

θ = angular size of the circle of confusion

L = effective diameter of lens = $\frac{\text{focal length of lens}}{\text{f-number of relative aperature}}$

With an object distance of 2.07 inches, a circle of confusion of 2 minutes of arc, a lens having a focal length of 1.97 inches, and a relative aperature number of f/8, the near and far field limits are calculated as 2.06 and 2.08 inches, respectively.

APPENDIX A-II

VISCOSITY AND SURFACE TENSION OF LIQUIDS USED

Tap Water at 22° C.

Trial	Viscosity (M°)*	Surface Tension (dynes/cm)
1	10	76.0
2	9	76.1
3	9	76.2
4		76.3
5		75.9
6		76.1
Average	9.3	76.1

1% Nigrosine Dye in Tap Water at 22° C.

Trial	Viscosity (M°)*	Surface Tension (dynes/cm)
1	11	54.5
2	10	54.2
3	11	54.3
4		54.3
5		54.1
6		54.1
Average	10.7	54.3

No. 2 Diesel Fuel at 22° C.

Trial	Viscosity (M°)*	Surface Tension (dynes/cm)
1	22	31.0
2	22	30.9
3	20	31.1
4		31.2
5		31.0
6		31.0
Average	21.3	31.0

* Degrees "M" is a relative measure of absolute viscosity as determined from the MacMichael Viscosimeter. The viscosity measurements shown were obtained for the following conditions: torsion wire no. 34; disc plunger with 3 cm liquid level; cup rotation of 14.75 rev/min.

APPENDIX B

DROP COLLECTION DATA FOR JET BREAKUP

DISPERSION PATTERN DATA FOR JET BREAKUP

ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)

Explanation of Tables

The numbers appearing in the tables in Appendix B-III are the measurements of drop size or movement taken from the optical comparator grid chart. These numbers can be converted into actual size using the following formula:

$$\text{Actual Size (mm)} = (\text{Grid Chart Reading})\frac{(\text{Grid Chart Constant mm/grid unit})}{(\text{Camera Mag.})(\text{Comparator Mag.})}$$

APPENDIX B-I

DROP COLLECTION DATA FOR JET BREAKUP

Delavan CS-1 (with core removed)
3 psi, water
1 kv., negative polarity

Run Number	Time of test (min)	Net weight of water collected, pounds	
		Beaker	Plastic bag
1	30	.01	1.20
2	30	.01	1.21
3	30	.01	1.20
4	30	.01	1.20
Average	30	.01	1.20

Spraying Systems X-1 (with core removed)
1 psi, water
2 kv., negative polarity

Run Number	Time of test (min)	Net weight of water collected, pounds	
		Beaker	Plastic bag
1	30	.03	2.90
2	30	.03	2.87
3	30	.03	2.78
4	30	.03	2.90
Average	30	.03	2.86

APPENDIX B-II

DISPERSION PATTERN DATA FOR JET BREAKUP

Delavan CS-1 (with core removed)
3 psi, water
negative polarity

1 KV. Time of test 9 minutes

Run	Net grams at each collection position one inch apart												
No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	6	9	13	16	18	18	17	16	15	12	8	3
2	0	3	8	12	16	19	20	19	17	15	13	7	2
3	2	4	9	14	18	20	20	19	16	15	13	8	2
4	1	5	10	14	18	19	19	18	16	15	13	7	3
5	1	5	9	13	17	19	19	18	16	15	13	8	3
Ave.	.8	4.6	9.0	13.2	17.0	19.0	19.2	18.2	16.2	15.0	12.8	7.6	2.6

No Voltage Time of test 2.5 minutes

Run	Net grams at each collection position one inch apart												
No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	0	1	7	18	13	3	0	0	0	0
2	0	0	0	0	1	7	19	13	4	1	0	0	0
3	0	0	0	0	1	5	19	15	3	1	0	0	0
4	0	0	0	0	1	4	21	15	4	1	0	0	0
5	0	0	0	0	1	7	17	14	3	1	0	0	0
Ave.	0	0	0	0	1	6	18.8	14.0	3.4	0.8	0	0	0

APPENDIX B-II CONTINUED

Spraying Systems X-1 (with core removed)
1 psi, water - negative polarity

2 KV. Time of test 4 minutes

Run No.	1	2	3	4	5	6	7	8	9	10	11	12	13
	Net grams at each collection position one inch apart												
1	4	9	12	13	16	18	18	17	16	14	11	7	2
2	5	10	12	13	15	17	18	17	16	14	12	8	3
3	4	9	12	14	15	17	19	18	16	14	11	8	3
4	4	9	12	13	16	18	19	18	17	15	12	8	3
5	5	10	11	13	15	17	19	18	17	16	13	9	3
Ave.	4.4	9.4	11.8	13.2	15.4	17.4	18.6	17.6	16.4	14.6	11.8	8.0	2.8

No Voltage Time of test 3.0 minutes

Run No.	1	2	3	4	5	6	7	8	9	10	11	12	13
	Net grams at each collection position one inch apart												
1					0	0	19	2	0				
2					0	1	18	2	0				
3					0	1	19	1	0				
4					0	2	19	1	0				
5					0	1	18	3	0				
Ave.					0	1.0	18.6	1.8	0				

APPENDIX B-III

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          ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
                 SPRAYING SYSTEMS X-1 (WITH CORE REMOVED)
                 ORIFICE DIAMETER = 530 MICRONS
                 WATER AT 1. PSI
                 COLLECTOR TUBE VOLTAGE = 2. KILOVOLTS
                 GRID CHART = 20. MM PER GRID UNIT
                 CAMERA MAG =  8.
                 COMPARATOR MAG = 10.
    NEGATIVE NUMBER  1.
MAJOR DIA LARGE 4.40 4.45 4.35 4.10 4.85 4.85
MINOR DIA LARGE 3.60 3.60 3.90 3.75 3.55 3.75
    NEGATIVE NUMBER  2.
MAJOR DIA LARGE 5.00 4.35 6.55 4.75
MINOR DIA LARGE 3.60 3.50 4.25 3.25
    NEGATIVE NUMBER  3.
MAJOR DIA LARGE 4.35 4.35 4.25 4.35
MINOR DIA LARGE 3.85 3.85 3.65 4.00
    NEGATIVE NUMBER  4.
MAJOR DIA LARGE 4.20 7.10 4.15
MINOR DIA LARGE 3.80 4.60 3.65
    NEGATIVE NUMBER  5.
MAJOR DIA LARGE 6.90 4.00 4.00 4.00 3.75
MINOR DIA LARGE 5.05 3.25 3.20 3.25 3.25
    NEGATIVE NUMBER  6.
MAJOR DIA LARGE 5.65 4.10 3.90 4.00
MINOR DIA LARGE 3.85 3.75 3.60 3.75
    NEGATIVE NUMBER  7.
MAJOR DIA LARGE 4.10 4.30 4.85 4.65 4.55
MINOR DIA LARGE 3.70 3.90 4.30 3.40 3.60
    NEGATIVE NUMBER  8.
MAJOR DIA LARGE 4.90 4.35 4.25 4.25 4.75
MINOR DIA LARGE 4.35 3.95 3.85 3.50 3.40
    NEGATIVE NUMBER  9.
MAJOR DIA LARGE 5.00 4.35 4.70 4.15
MINOR DIA LARGE 4.40 3.20 3.70 3.50
    NEGATIVE NUMBER 10.
MAJOR DIA LARGE 4.60 5.00 4.70
MINOR DIA LARGE 3.25 3.70 3.60
    NEGATIVE NUMBER 11.
MAJOR DIA LARGE 4.35 4.70 4.20 4.60 5.00
MINOR DIA LARGE 3.70 3.65 3.80 3.60 4.00
    NEGATIVE NUMBER 12.
MAJOR DIA LARGE 4.50 6.25 4.10 4.10 4.25
MINOR DIA LARGE 3.50 3.85 3.80 3.40 3.10
    NEGATIVE NUMBER 13.
MAJOR DIA LARGE 6.75 4.65 4.15 4.75
MINOR DIA LARGE 5.35 3.45 3.50 3.15
    NEGATIVE NUMBER 14.
MAJOR DIA LARGE 4.55 4.85 4.25 4.65 4.50 4.40
MINOR DIA LARGE 4.40 3.30 4.10 3.50 3.35 3.50
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        ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
               SPRAYING SYSTEMS X-1 (WITH CORE REMOVED)
               ORIFICE DIAMETER = 530 MICRONS
               WATER AT 1. PSI
               COLLECTOR TUBE VOLTAGE = 2. KILOVOLTS
               FLASH DELAY = 170. MICROSECONDS
               GRID CHART = 20. MM PER GRID UNIT
               CAMERA MAG =  8.
               COMPARATOR MAG = 10.
    NEGATIVE NUMBER 15.
MAJOR DIA LARGE 4.20 4.20 4.50 4.50 4.45
MINOR DIA LARGE 4.10 3.70 3.60 3.60 3.85
LGE DRP MOVMT.  2.80 2.90 2.75 2.85 2.90
    NEGATIVE NUMBER 16.
MAJOR DIA LARGE 4.40 4.75
MINOR DIA LARGE 3.50 3.75
LGE DRP MOVMT.  2.40 2.60
    NEGATIVE NUMBER 17.
MAJOR DIA LARGE 4.00 3.60
MINOR DIA LARGE 3.60 3.40
LGE DRP MOVMT.  2.30 2.00
    NEGATIVE NUMBER 18.
MAJOR DIA LARGE 4.10 4.40
MINOR DIA LARGE 3.25 4.10
LGE DRP MOVMT.  2.45 2.65
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         ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
                SPRAYING SYSTEMS X-1 (WITH CORE REMOVED)
                ORIFICE DIAMETER = 530 MICRONS
                WATER AT 1. PSI
                GRID CHART = 20. MM PER GRID UNIT
                CAMERA MAG =  8.
                COMPARATOR MAG = 10.
    NEGATIVE NUMBER  1.
MAJOR DIA LARGE 5.15 5.20 6.15 4.35
MINOR DIA LARGE 3.35 3.25 3.55 3.90
DIAMETER SMALL  1.00
    NEGATIVE NUMBER  2.
MAJOR DIA LARGE 5.30 5.30 4.60 5.10 4.60
MINOR DIA LARGE 3.35 3.55 4.10 3.00 3.30
DIAMETER SMALL  1.20 1.25
    NEGATIVE NUMBER  3.
MAJOR DIA LARGE 4.35 4.40 3.60 3.90 4.00
MINOR DIA LARGE 4.00 3.25 3.05 3.70 3.55
DIAMETER SMALL   .07  .05  .09
    NEGATIVE NUMBER  4.
MAJOR DIA LARGE 4.75 4.50 4.95 4.45 4.90
MINOR DIA LARGE 3.50 3.05 3.20 3.75 3.00
DIAMETER SMALL  1.40 1.00
    NEGATIVE NUMBER  5.
MAJOR DIA LARGE 5.50 5.30 4.65 4.50
MINOR DIA LARGE 3.30 3.50 3.25 4.15
DIAMETER SMALL   .06  .11  .07  .09
    NEGATIVE NUMBER  6.
MAJOR DIA LARGE 5.90 5.95 4.90
MINOR DIA LARGE 3.30 4.40 3.50
DIAMETER SMALL  1.42 1.25
    NEGATIVE NUMBER  7.
MAJOR DIA LARGE 5.75 5.30 5.35 4.60
MINOR DIA LARGE 3.10 3.05 4.10 3.50
DIAMETER SMALL  1.15
    NEGATIVE NUMBER  8.
MAJOR DIA LARGE 5.90 4.80 4.50 5.00
MINOR DIA LARGE 4.50 3.10 3.30 3.50
DIAMETER SMALL  1.20  .07
    NEGATIVE NUMBER  9.
MAJOR DIA LARGE 5.15 4.70 5.85 4.75
MINOR DIA LARGE 2.75 3.55 3.50 3.90
DIAMETER SMALL  1.20
    NEGATIVE NUMBER 10.
MAJOR DIA LARGE 5.60 5.05 6.20 4.85
MINOR DIA LARGE 3.30 3.50 3.60 3.50
DIAMETER SMALL  1.15 1.25  .40
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```
        ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
               SPRAYING SYSTEMS X-1 (WITH CORE REMOVED)
               ORIFICE DIAMETER = 530 MICRONS
               WATER AT 1. PSI
               FLASH DELAY = 170. MICROSECONDS
               GRID CHART = 20. MM PER GRID UNIT
               CAMERA MAG =  8.
               COMPARATOR MAG = 10.
    NEGATIVE NUMBER 18.
MAJOR OIA LARGE 5.75 4.00 6.00 5.50 5.00 4.50
MINOR DIA LARGE 3.15 3.75 3.90 3.00 4.25 3.00
DIAMETER SMALL  1.00
    NEGATIVE NUMBER 11.
MAJOR OIA LARGE 4.50 5.05 5.50 5.05 5.30
MINOR DIA LARGE 3.25 3.60 3.50 3.75 3.60
DIAMETER SMALL  1.20 1.27 1.07
LGE DRP MOVMT.  2.65 2.55 2.50 2.45 2.60
SML DRP MOVMT.  2.75 2.65 2.75
    NEGATIVE NUMBER 12.
MAJOR OIA LARGE 5.25 5.90 4.75 5.10 5.70
MINOR DIA LARGE 3.05 4.25 2.95 3.30 3.60
DIAMETER SMALL  1.00
LGE DRP MOVMT.  2.45 2.75 2.35 2.50 2.15
SML DRP MOVMT.  2.40
    NEGATIVE NUMBER 13.
MAJOR OIA LARGE 4.20 4.85 5.75
MINOR DIA LARGE 4.15 3.60 3.25
DIAMETER SMALL   .09 1.50 1.25
LGE DRP MOVMT.  2.40 2.40 2.40
SML DRP MOVMT.  2.40 2.80 2.50
    NEGATIVE NUMBER 14.
MAJOR OIA LARGE 6.80 4.20 5.75
MINOR DIA LARGE 3.50 3.90 3.90
DIAMETER SMALL  1.20  .08
LGE DRP MOVMT.  2.60 2.55 2.60
SML DRP MOVMT.  2.50 2.40
    NEGATIVE NUMBER 15.
MAJOR OIA LARGE 4.25 4.50 4.75 4.15
MINOR DIA LARGE 4.05 3.85 3.95 4.05
DIAMETER SMALL  1.15
LGE DRP MOVMT.  2.50 2.40 2.50 2.40
SML DRP MOVMT.  2.25
    NEGATIVE NUMBER 16.
MAJOR OIA LARGE 4.40 5.25 4.50 4.50 4.60
MINOR DIA LARGE 3.35 3.50 3.70 3.60 4.00
DIAMETER SMALL  1.27
LGE DRP MOVMT.  2.65 2.15 2.60 2.40 2.60
SML DRP MOVMT.  2.50
    NEGATIVE NUMBER 17.
MAJOR OIA LARGE 4.40 4.45 4.40 4.35 4.70
MINOR DIA LARGE 3.95 3.50 3.00 3.10 3.55
DIAMETER SMALL  1.25
LGE DRP MOVMT.  2.50 2.40 2.40 2.45 2.50
SML DRP MOVMT.  2.40
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APPENDIX B-III CONTINUED

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          ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
                 DELAVAN CS-1 (WITH CORE REMOVED)
                 ORIFICE DIAMETER = 250 MICRONS
                 WATER AT 3. PSI
                 COLLECTOR TUBE VOLTAGE = 1. KILOVOLTS
                 GRID CHART = 20. MM PER GRID UNIT
                 CAMERA MAG =  8.
                 COMPARATOR MAG = 10.
       NEGATIVE NUMBER 19.
   MAJOR OIA LARGE 2.10 2.20 2.10 2.05 1.90 2.20
   MINOR DIA LARGE 2.00 2.10 2.00 1.95 1.95 2.15
       NEGATIVE NUMBER 20.
   MAJOR OIA LARGE 2.00 2.55 2.00 2.00 2.10
   MINOR DIA LARGE 2.00 2.50 1.85 2.00 2.00
       NEGATIVE NUMBER 21.
   MAJOR OIA LARGE 2.00 2.15 1.75 1.95
   MINOR DIA LARGE 1.95 2.00 1.70 1.90
       NEGATIVE NUMBER 22.
   MAJOR OIA LARGE 2.55 1.95 2.80 2.05 2.05 2.05 2.00 2.70 2.05
   MINOR DIA LARGE 2.35 1.95 2.60 2.00 2.05 2.00 2.00 2.65 2.00
       NEGATIVE NUMBER 24.
   MAJOR OIA LARGE 2.25 2.10 2.05 2.05 2.10 1.80
   MINOR DIA LARGE 2.25 2.00 2.00 2.00 2.10 1.75
       NEGATIVE NUMBER 25.
   MAJOR OIA LARGE 2.65 2.25
   MINOR DIA LARGE 2.60 2.15
       NEGATIVE NUMBER 26.
   MAJOR OIA LARGE 2.25 2.45 2.05 1.90 2.00 2.45 2.00 2.00
   MINOR DIA LARGE 2.15 2.15 1.95 1.60 1.95 2.25 2.00 2.00
       NEGATIVE NUMBER 27.
   MAJOR OIA LARGE 2.90 1.95 2.05 1.90 1.90 1.90 1.90 1.80
   MINOR DIA LARGE 2.55 1.90 2.05 1.80 1.75 1.80 1.75 1.80
       NEGATIVE NUMBER 28.
   MAJOR OIA LARGE 2.10 3.00 2.00 2.00 2.60
   MINOR DIA LARGE 1.95 2.90 1.95 2.00 2.40
       NEGATIVE NUMBER 29.
   MAJOR OIA LARGE 2.15 2.05 2.05 2.00 1.80 2.00 2.40
   MINOR DIA LARGE 2.15 1.95 2.00 1.90 1.75 1.90 2.30
       NEGATIVE NUMBER 30.
   MAJOR OIA LARGE 2.05 2.10 2.95 2.00 2.00 2.10
   MINOR DIA LARGE 2.05 2.00 2.60 1.75 2.00 2.00
       NEGATIVE NUMBER 31.
   MAJOR OIA LARGE 2.10 2.15 2.90 2.15 2.10 2.00 2.10
   MINOR DIA LARGE 2.05 2.10 2.60 2.10 2.10 2.00 2.10
       NEGATIVE NUMBER 32.
   MAJOR OIA LARGE 3.00 2.05 2.00 2.00 2.00 2.10 2.00
   MINOR DIA LARGE 2.90 2.00 2.00 1.80 2.00 2.00 2.00
```

APPENDIX B-III CONTINUED

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         ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
                DELAVAN CS-1 (WITH CORE REMOVED)
                ORIFICE DIAMETER = 250 MICRONS
                WATER AT 3. PSI
                COLLECTOR TUBE VOLTAGE = 1. KILOVOLTS
                FLASH DELAY = 170. MICROSECONDS
                GRID CHART = 20. MM PER GRID UNIT
                CAMERA MAG =  8.
                COMPARATOR MAG = 10.
    NEGATIVE NUMBER 33.
MAJOR OIA LARGE 2.05 2.10 2.60 2.00
MINOR DIA LARGE 1.95 2.00 2.50 2.00
LGE DRP MOVMT.  4.15 4.10 4.50 4.05
    NEGATIVE NUMBER 34.
MAJOR OIA LARGE 2.05 2.45 2.70 2.00 1.95 2.10 2.10
MINOR DIA LARGE 1.95 2.30 2.55 1.95 1.90 2.00 2.00
LGE DRP MOVMT.  4.20 4.30 4.25 4.25 4.20 4.25 4.30
    NEGATIVE NUMBER 35.
MAJOR OIA LARGE 2.65 2.30 2.15 2.00 2.00 2.05
MINOR DIA LARGE 2.20 2.25 2.00 2.00 2.00 2.05
LGE DRP MOVMT.  4.15 4.20 4.30 4.10 4.25 4.10
    NEGATIVE NUMBER 36.
MAJOR OIA LARGE 2.85 2.05 2.00
MINOR DIA LARGE 2.70 2.05 2.00
LGE DRP MOVMT.  4.40 2.30 4.10
```

APPENDIX B-III CONTINUED

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        ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
                DELAVAN CS-1 (WITH CORE REMOVED)
                ORIFICE DIAMETER = 250 MICRONS
                WATER AT 3. PSI
                GRID CHART = 20. MM PER GRID UNIT
                CAMERA MAG =  8.
                COMPARATOR MAG = 10.
     NEGATIVE NUMBER 19.
 MAJOR OIA LARGE 2.10 2.15 2.35 2.50 2.05 2.20 1.95 2.15 2.10 2.40 2.60
 MINOR DIA LARGE 1.90 1.60 1.75 1.75 1.85 1.55 1.85 1.75 1.85 1.80 1.80
     NEGATIVE NUMBER 20.
 MAJOR OIA LARGE 2.00 2.00 2.25 2.30 2.15 2.80 2.15 2.50
 MINOR DIA LARGE 1.50 2.00 1.50 1.80 2.00 2.00 1.80 1.75
 DIAMETER SMALL   .07
     NEGATIVE NUMBER 21.
 MAJOR OIA LARGE 3.80 2.30 2.55 2.25 2.25 2.25 2.55 2.30 2.70
 MINOR DIA LARGE 1.95 1.50 1.75 1.80 1.10 1.95 1.75 1.90 2.25
     NEGATIVE NUMBER 22.
 MAJOR OIA LARGE 2.10 2.25 2.10 2.45 2.25 2.00 2.25 2.00 2.15 2.50 2.15
 MINOR DIA LARGE 1.75 1.90 2.00 1.80 1.90 1.90 1.90 1.85 1.85 1.75 1.75
 DIAMETER SMALL   .08
     NEGATIVE NUMBER 23.
 MAJOR OIA LARGE 2.50 2.25 2.20 2.30 3.85 2.35 2.35 2.35 2.15
 MINOR DIA LARGE 1.75 1.80 1.75 1.60 1.85 1.95 1.85 1.80 1.90
     NEGATIVE NUMBER 24.
 MAJOR OIA LARGE 2.35 2.25 2.90 2.30 3.15 2.10 2.00 2.55 2.30
 MINOR DIA LARGE 1.80 1.90 2.45 2.00 1.90 1.80 1.90 1.75 2.00
 DIAMETER SMALL   .05  .07
     NEGATIVE NUMBER 25.
 MAJOR OIA LARGE 2.25 2.30 2.60 3.15 2.25 2.00 2.30 2.15 2.05 2.45 2.60 2.20
 MINOR DIA LARGE 1.75 1.70 1.70 2.00 1.75 1.95 1.90 1.75 2.00 1.75 2.30 1.85
     NEGATIVE NUMBER 26.
 MAJOR OIA LARGE 2.40 2.15 3.00 2.10 2.40 2.50 2.10 4.50 2.65
 MINOR DIA LARGE 1.70 1.90 2.70 1.80 1.75 1.70 1.65 1.60 1.70
 DIAMETER SMALL   .07
     NEGATIVE NUMBER 27.
 MAJOR OIA LARGE 2.55 2.50 2.95 2.15 2.15 2.00 2.10 2.75 2.50 2.00
 MINOR DIA LARGE 1.70 1.75 1.60 1.65 2.00 1.90 1.90 1.80 1.75 1.90
     NEGATIVE NUMBER 28.
 MAJOR OIA LARGE 2.20 2.05 2.30 2.25 2.50 2.15 2.30 2.25 2.90 2.15
 MINOR DIA LARGE 1.80 1.70 1.90 1.50 1.80 1.70 1.85 1.90 2.15 1.85
 DIAMETER SMALL   .03
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APPENDIX B-III CONTINUED

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        ELECTROSTATIC JET DISPERSION DATA (GRID READINGS)
              DELAVAN CS-1 (WITH CORE REMOVED)
              ORIFICE DIAMETER = 250 MICRONS
              WATER AT 3. PSI
              FLASH DELAY = 100. MICROSECONDS
              GRID CHART = 20. MM PER GRID UNIT
              CAMERA MAG =  8.
              COMPARATOR MAG = 10.
    NEGATIVE NUMBER 32.
MAJOR DIA LARGE 2.00 2.15 2.60 2.00 2.50 1.95 2.25 2.45 2.45 2.25 2.35
MINOR DIA LARGE 1.75 1.85 1.75 2.00 2.25 1.70 1.90 1.85 1.80 1.90 1.85
DIAMETER SMALL   .06
    NEGATIVE NUMBER 29.
MAJOR DIA LARGE 2.00 2.00 2.15 2.35 2.50 2.10 2.75 2.25 2.05 2.15
MINOR DIA LARGE 2.00 1.85 1.95 2.00 1.75 1.70 2.35 1.75 1.75 1.50
LGE DRP MOVMT.  2.35 2.40 2.50 2.60 2.50 2.50 2.40 2.50 2.50 2.40
    NEGATIVE NUMBER 30.
MAJOR DIA LARGE 2.75 2.60 3.00 2.70 2.00 2.45 2.15 2.50 2.55
MINOR DIA LARGE 2.00 1.70 1.70 1.75 2.00 1.80 1.65 1.75 1.80
LGE DRP MOVMT.  2.25 2.50 2.35 2.45 2.60 2.40 2.40 2.50 2.40
    NEGATIVE NUMBER 31.
MAJOR DIA LARGE 2.40 2.25 2.60 2.00 2.10 2.15 2.30 2.50 2.15 3.30 2.05
MINOR DIA LARGE 1.55 1.90 1.75 1.90 1.75 1.65 1.85 1.70 1.85 1.90 1.85
LGE DRP MOVMT.  2.55 2.40 2.35 2.40 2.50 2.50 2.45 2.35 2.45 2.50 2.45
    NEGATIVE NUMBER 33.
MAJOR DIA LARGE 2.10 2.90 2.50 3.05 2.00 3.60 2.00 2.05 2.10
MINOR DIA LARGE 1.80 1.85 1.75 2.50 2.00 2.10 1.75 1.55 1.90
DIAMETER SMALL   .06
LGE DRP MOVMT.  2.45 2.45 2.35 2.40 2.40 2.35 2.35 2.40 2.30
SML DRP MOVMT.  2.40
    NEGATIVE NUMBER 34.
MAJOR DIA LARGE 2.10 2.45 2.20 2.00 2.55 2.10 2.05 2.40 2.25 2.60 2.50 2.20
MINOR DIA LARGE 2.00 1.80 1.90 1.95 1.75 1.75 1.75 1.75 1.90 2.35 1.80 1.60
DIAMETER SMALL   .08
LGE DRP MOVMT.  2.40 2.35 2.35 2.40 2.35 2.50 2.40 2.50 2.15 2.45 2.40 2.35
SML DRP MOVMT.  2.10
    NEGATIVE NUMBER 35.
MAJOR DIA LARGE 2.50 2.75 2.05 2.50 2.20 2.25 2.20 2.35 2.10 2.55
MINOR DIA LARGE 1.85 2.10 1.90 1.75 1.60 1.65 1.80 1.80 2.05 1.75
LGE DRP MOVMT.  2.40 2.50 2.50 2.50 2.35 2.40 2.40 2.50 2.50 2.45
    NEGATIVE NUMBER 36.
MAJOR DIA LARGE 2.45 2.10 2.00 2.15 2.00 2.20 2.25 2.20 2.05 2.00 2.05
MINOR DIA LARGE 1.80 1.85 1.75 1.90 2.00 1.55 1.85 1.90 1.75 2.00 1.95
LGE DRP MOVMT.  2.60 2.40 2.35 2.65 2.60 2.35 2.35 2.35 2.25 2.40 2.35
```

APPENDIX C

SAMPLING LOCATION DATA

Explanation of Tables

The numbers appearing in the following tables are the measurements of drop diameter and movement taken from the optical comparator grid chart. The flash delay shown at the top of each sheet is the time during which the movement shown occurred. The numbers can be converted to actual size using equation 7-1 and the following:

$$\text{Actual Size (mm)} = (\text{Grid Chart Reading})\frac{(\text{Grid Chart Constant mm/grid unit})}{(\text{Camera Mag.})(\text{Comparator Mag.})}$$

APPENDIX C

```
                    SAMPLING LOCATION DATA

                    WATER AT 40 PSI
                    GRID CHART = 20 MM PER GRID UNIT
                    COMPARATOR MAG. = 10
                    CAMERA MAG. = 10.
                    FLASH DELAY = 25 MICROSECONDS

   SAMPLING DISTANCE =  1.5          NEGATIVE NUMBER =  1.
DIAMETER (GRID) 1.00  .20  .40  .75  .50  .20  .75  .40  .80  .50
MOVEMENT (GRID) 1.85 1.70 1.85 1.80 2.10 1.75 2.00 2.10 2.20 2.00
DIAMETER (GRID) 1.00  .75 1.10  .15  .50  .50  .50  .50  .50
MOVEMENT (GRID) 2.25 2.25 2.00 1.40 2.15 2.15 2.15 2.25 2.25

   SAMPLING DISTANCE =  1.5          NEGATIVE NUMBER =  2.
DIAMETER (GRID)  .15  .20  .30  .25  .65  .55  .45  .25  .15  .50
MOVEMENT (GRID) 1.70 1.70 2.25 2.00 2.25 1.80 2.40 1.70 1.65 2.15
DIAMETER (GRID)  .20  .25  .65  .70  .40  .25  .90  .35
MOVEMENT (GRID) 1.85 1.85 2.25 2.30 2.00 2.05 2.20 2.05

   SAMPLING DISTANCE =  1.5          NEGATIVE NUMBER =  3.
DIAMETER (GRID)  .50  .95  .50  .25  .35  .50  .35  .50  .50  .55
MOVEMENT (GRID) 2.30 2.35 1.75 2.05 2.00 2.35 2.40 2.25 2.10 2.10
DIAMETER (GRID)  .80 1.20 1.00  .50  .20  .80  .65  .50  .50  .70
MOVEMENT (GRID) 2.00 2.20 2.30 2.25 1.40 2.35 2.35 2.20 2.25 2.40
DIAMETER (GRID)  .45  .50  .40  .65  .60 1.00  .85
MOVEMENT (GRID) 2.25 2.30 2.20 2.50 2.55 2.15 2.65

   SAMPLING DISTANCE =  1.5          NEGATIVE NUMBER =  4.
DIAMETER (GRID)  .30  .40  .30  .60  .45  .30  .50  .25  .60  .75
MOVEMENT (GRID) 2.10 1.85 1.95 2.50 1.85 2.30 2.00 1.80 2.15 2.00
DIAMETER (GRID)  .25
MOVEMENT (GRID) 2.00
```

APPENDIX C CONTINUED

```
                        SAMPLING LOCATION DATA

                        WATER AT 40 PSI
                        GRID CHART = 20 MM PER GRID UNIT
                        COMPARATOR MAG. = 10
                        CAMERA MAG. = 10.
                        FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  1.
DIAMETER (GRID)  .30  .50  .75 1.00  .50  .50  .25  .50  .30  .90
MOVEMENT (GRID) 1.80 2.10 2.10 2.25 2.20 2.15 1.60 2.20 1.50 2.25
DIAMETER (GRID)  .30  .25
MOVEMENT (GRID) 2.05 1.90

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  2.
DIAMETER (GRID)  .40 1.25  .20  .15  .25  .25  .75 1.30  .35  .15
MOVEMENT (GRID) 2.30 2.00  .65  .60 2.25 1.40 2.30 2.30 1.85  .90
DIAMETER (GRID)  .35
MOVEMENT (GRID) 1.50

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  5.
DIAMETER (GRID)  .15  .20  .15  .70  .35  .45  .30  .25  .75  .15
MOVEMENT (GRID)  .40 1.15  .35 1.90 1.80 1.65 1.70 1.75 2.20 1.10
DIAMETER (GRID)  .30
MOVEMENT (GRID) 1.90

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  6.
DIAMETER (GRID)  .20  .15  .65  .80  .25  .50  .75  .70  .40  .40
MOVEMENT (GRID) 1.10  .45 2.10 2.25 1.75 1.60 1.85 2.00 1.75 1.50

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  7.
DIAMETER (GRID)  .30  .35  .35  .25  .35  .50 1.15  .25  .35  .65
MOVEMENT (GRID) 1.30  .50  .45  .20 2.30  .20 2.10  .45  .70 1.50
DIAMETER (GRID)  .50  .30  .20  .50  .75  .40  .25
MOVEMENT (GRID) 1.45  .50  .55 2.00 2.15 1.75 1.20

    SAMPLING DISTANCE =  2.5           NEGATIVE NUMBER =  8.
DIAMETER (GRID)  .25  .15  .50  .15  .30
MOVEMENT (GRID) 1.40 1.85 2.15  .35  .95
```

APPENDIX C CONTINUED

```
                   SAMPLING LOCATION DATA

                   WATER AT 40 PSI
                   GRID CHART = 20 MM PER GRID UNIT
                   COMPARATOR MAG. = 10
                   CAMERA MAG. = 10.
                   FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  3.5          NEGATIVE NUMBER =  9.
DIAMETER (GRID)  .45  .20  .15  .30
MOVEMENT (GRID) 1.85  .50  .50  .95

    SAMPLING DISTANCE =  3.5          NEGATIVE NUMBER = 10.
DIAMETER (GRID)  .25  .10  .45  .75  .35  .30  .30  .25  .20  .50
MOVEMENT (GRID)  .90  .45 1.35 2.05 1.35  .90  .75  .40  .55 1.45

    SAMPLING DISTANCE =  3.5          NEGATIVE NUMBER = 11.
DIAMETER (GRID)  .30  .10  .75  .25  .60  .15  .20  .25  .15
MOVEMENT (GRID)  .75  .40 1.95  .45 1.60  .40  .45 1.10  .60

    SAMPLING DISTANCE =  3.5          NEGATIVE NUMBER = 12.
DIAMETER (GRID)  .15  .40  .25  .80  .15  .20  .30
MOVEMENT (GRID)  .50 1.55  .80 1.90  .75  .90 1.15
```

APPENDIX C CONTINUED

```
                   SAMPLING LOCATION DATA

                   WATER AT 40 PSI
                   GRID CHART = 20 MM PER GRID UNIT
                   COMPARATOR MAG. = 10
                   CAMERA MAG. = 10.
                   FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER =  4.
DIAMETER (GRID)  .30  .25 1.00  .20  .20
MOVEMENT (GRID)  .75  .30 1.70  .15  .20

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER = 12.
DIAMETER (GRID)  .25  .25  .25  .20  .20  .30  .20  .60  .65  .25
MOVEMENT (GRID)  .30  .65  .70  .45  .30 1.25  .70 1.50 1.75  .50
DIAMETER (GRID)  .80  .25  .25 1.00
MOVEMENT (GRID) 1.95  .60  .65 2.00

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER = 13.
DIAMETER (GRID)  .40  .50  .60  .25  .50  .35  .35  .80  .25  .20
MOVEMENT (GRID) 1.00 1.50 1.50  .80 1.75 1.05  .75 1.60  .55  .55
DIAMETER (GRID)  .80  .25  .10  .25
MOVEMENT (GRID) 1.90  .45  .40  .55

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER = 14.
DIAMETER (GRID)  .40  .35
MOVEMENT (GRID) 1.15  .45

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER = 15.
DIAMETER (GRID)  .20  .40  .25  .25  .20  .25  .20
MOVEMENT (GRID)  .45 1.50  .70  .75  .45  .75  .50

    SAMPLING DISTANCE =  4.5          NEGATIVE NUMBER = 16.
DIAMETER (GRID)  .75  .25  .20  .25  .35  .55  .80
MOVEMENT (GRID) 1.50  .80  .30  .60  .75  .80 1.80
```

APPENDIX C CONTINUED

```
                        SAMPLING LOCATION DATA

                        WATER AT 40 PSI
                        GRID CHART = 20 MM PER GRID UNIT
                        COMPARATOR MAG. = 10
                        CAMERA MAG. = 10.
                        FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  5.5           NEGATIVE NUMBER = 17.
DIAMETER (GRID)  .25  .15  .20  .20  .30  .30  .35  .35  .35  .15
MOVEMENT (GRID)  .45  .35  .30  .50  .75  .60  .60  .75  .70  .40

    SAMPLING DISTANCE =  5.5           NEGATIVE NUMBER = 18.
DIAMETER (GRID)  .25  .30
MOVEMENT (GRID)  .30  .25

    SAMPLING DISTANCE =  5.5           NEGATIVE NUMBER = 19.
DIAMETER (GRID)  .60  .25  .30 1.00  .90
MOVEMENT (GRID) 1.20  .50  .55 1.95 1.90

    SAMPLING DISTANCE =  5.5           NEGATIVE NUMBER = 20.
DIAMETER (GRID)  .85  .25
MOVEMENT (GRID) 1.50  .30
```

APPENDIX C CONTINUED

```
                   SAMPLING LOCATION DATA

                   WATER AT 40 PSI
                   GRID CHART = 20 MM PER GRID UNIT
                   CCMPARATOR MAG. = 10
                   CAMERA MAG. = 10.
                   FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER =  5.
DIAMETER (GRID)  .75  .35  .35  .40  .45
MOVEMENT (GRID) 1.25  .15  .15  .30  .60

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER =  6.
DIAMETER (GRID)  .30  .70  .25
MOVEMENT (GRID)  .25 1.25  .75

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER = 21.
DIAMETER (GRID)  .25  .45  .20  .20  .30  .60  .30  .25  .30
MOVEMENT (GRID)  .30  .25  .30  .35  .55 1.10  .25  .50  .50

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER = 22.
DIAMETER (GRID)  .35  .30  .50  .30  .60  .15
MOVEMENT (GRID)  .15  .20 1.10  .50 1.20  .25

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER = 23.
DIAMETER (GRID)  .50  .40  .30  .30  .25  .55
MOVEMENT (GRID)  .65  .75  .45  .65  .45 1.10

    SAMPLING DISTANCE =  6.5          NEGATIVE NUMBER = 24.
DIAMETER (GRID)  .35  .20
MOVEMENT (GRID)  .50  .30
```

```
                    SAMPLING LOCATION DATA

                    WATER AT 40 PSI
                    GRID CHART = 20 MM PER GRID UNIT
                    COMPARATOR MAG. = 10
                    CAMERA MAG. = 10.
                    FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER =  3.
DIAMETER (GRID)  .30  .25  .20  .15  .15  .10
MOVEMENT (GRID)  .35  .30  .35  .30  .35  .35

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER =  7.
DIAMETER (GRID)  .15  .35  .45  .20  .30
MOVEMENT (GRID)  .20  .40  .25  .25  .35

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER =  8.
DIAMETER (GRID)  .60  .35  .25
MOVEMENT (GRID)  .70  .25  .50

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER =  9.
DIAMETER (GRID)  .75  .45  .60
MOVEMENT (GRID) 1.00  .10  .95

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER = 10.
DIAMETER (GRID)  .30  .35  .40
MOVEMENT (GRID)  .15  .25  .25

    SAMPLING DISTANCE =  8.5            NEGATIVE NUMBER = 11.
DIAMETER (GRID)  .35  .65  .60  .30  .40  .50
MOVEMENT (GRID)  .15  .80  .85  .40  .25  .75
```

APPENDIX C CONTINUED

```
                    SAMPLING LOCATION DATA

                    WATER AT 40 PSI
                    GRID CHART = 20 MM PER GRID UNIT
                    COMPARATOR MAG. = 10
                    CAMERA MAG. = 10.
                    FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE = 10.5          NEGATIVE NUMBER = 13.
DIAMETER (GRID)  .25  .35  .75
MOVEMENT (GRID)  .10  .15  .30

    SAMPLING DISTANCE = 10.5          NEGATIVE NUMBER = 14.
DIAMETER (GRID)  .30
MOVEMENT (GRID)  .15

    SAMPLING DISTANCE = 10.5          NEGATIVE NUMBER = 15.
DIAMETER (GRID)  .65  .30
MOVEMENT (GRID)  .65  .40

    SAMPLING DISTANCE = 10.5          NEGATIVE NUMBER = 16.
DIAMETER (GRID)  .70  .40  .25
MOVEMENT (GRID)  .80  .15  .15

    SAMPLING DISTANCE = 10.5          NEGATIVE NUMBER = 17.
DIAMETER (GRID)  .70  .65  .25
MOVEMENT (GRID)  .80  .80  .35
```

```
                SAMPLING LOCATION DATA

                WATER AT 40 PSI
                GRID CHART = 20 MM PER GRID UNIT
                COMPARATOR MAG. = 10
                CAMERA MAG. = 10.
                FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE = 12.5            NEGATIVE NUMBER = 20.
DIAMETER (GRID)  .85
MOVEMENT (GRID)  .50

    SAMPLING DISTANCE = 12.5            NEGATIVE NUMBER = 21.
DIAMETER (GRID)  .35
MOVEMENT (GRID)  .25

    SAMPLING DISTANCE = 12.5            NEGATIVE NUMBER = 22.
DIAMETER (GRID)  .25
MOVEMENT (GRID)  .05

    SAMPLING DISTANCE = 12.5            NEGATIVE NUMBER = 24.
DIAMETER (GRID)  .50  .35
MOVEMENT (GRID)  .30  .25
```

APPENDIX C CONTINUED

```
                    SAMPLING LOCATION DATA

                    DIESEL OIL AT 20 PSI
                    GRID CHART = 20 MM PER GRID UNIT
                    COMPARATOR MAG. = 10
                    CAMERA MAG. =  8.
                    FLASH DELAY = 25 MICROSECONDS

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 19.
DIAMETER (GRID)  .30  .45  .20  .30  .25  .25  .20  .45  .30  .25
MOVEMENT (GRID)  .85  .95 1.30 1.00 1.60 1.50 1.30 1.75 1.50 1.50
DIAMETER (GRID)  .35  .50  .15  .10  .35  .15  .45  .25  .40  .40
MOVEMENT (GRID) 1.75 1.80 1.70 1.40 1.70 1.40 1.65 1.75 1.65 1.65
DIAMETER (GRID)  .15  .10  .10  .60  .15  .25  .50
MOVEMENT (GRID) 1.25 1.65 1.35 1.45 1.10  .80  .90

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 20.
DIAMETER (GRID)  .35  .40  .15  .50 1.10  .20  .15  .20  .35  .30
MOVEMENT (GRID) 1.75 1.25 1.00 1.60 2.50  .95 1.40 1.40 1.10 1.45
DIAMETER (GRID)  .25  .20  .20  .65  .45  .30  .40  .35  .45  .70
MOVEMENT (GRID) 1.25 1.40 1.55 1.00 1.20 1.40 1.45 1.30 1.05 1.00
DIAMETER (GRID)  .30  .30  .25  .15  .40  .50
MOVEMENT (GRID) 1.30 1.30 1.05 1.00 1.35 1.05

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 21.
DIAMETER (GRID)  .45  .35  .60  .40
MOVEMENT (GRID) 1.65 1.60 1.00 1.90

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 22.
DIAMETER (GRID)  .50  .75  .65  .50  .50  .55  .45  .70  .55  .65
MOVEMENT (GRID) 1.05 1.10  .70 1.55 1.25 1.70 1.50 1.00 1.00 1.45
DIAMETER (GRID)  .30  .25  .45  .60  .50  .40  .45  .45  .20  .35
MOVEMENT (GRID) 1.40 1.25 1.50 1.45 1.15 1.35 1.75 1.10  .65  .90

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 23.
DIAMETER (GRID)  .30  .30  .25  .35  .25  .50  .65  .65  .55  .40
MOVEMENT (GRID) 1.75 1.30 1.60 1.55 1.75 1.50 2.00 1.45 2.00 1.15
DIAMETER (GRID)  .45
MOVEMENT (GRID) 1.05

   SAMPLING DISTANCE =  3.0          NEGATIVE NUMBER = 24.
DIAMETER (GRID)  .35  .25  .25  .60  .35  .40  .25  .25  .30  .35
MOVEMENT (GRID) 1.05 1.20  .60 1.00 1.50 1.40 1.35 1.40 1.75 1.40
DIAMETER (GRID)  .35  .25
MOVEMENT (GRID) 1.55  .75
```

APPENDIX C CONTINUED

```
                SAMPLING LOCATION DATA

                DIESEL OIL AT 20 PSI
                GRID CHART = 20 MM PER GRID UNIT
                COMPARATOR MAG. = 10
                CAMERA MAG. =  8.
                FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 25.
DIAMETER (GRID)  .50  .40  .25  .25  .25  .25  .20  .25  .25  .30
MOVEMENT (GRID)  .60  .70  .45  .50  .50  .60  .20  .30  .90 1.00
DIAMETER (GRID)  .55  .30  .20  .30
MOVEMENT (GRID) 1.20  .95  .90 1.10

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 26.
DIAMETER (GRID) 7.00  .55  .30  .50  .40  .50  .25  .40  .25  .20
MOVEMENT (GRID) 1.55 1.50  .90 1.70 1.05 1.75  .35  .70 1.15  .60
DIAMETER (GRID)  .50  .35  .25  .25  .25  .20  .20
MOVEMENT (GRID) 1.35 1.85  .40  .85  .45  .30  .40

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 27.
DIAMETER (GRID)  .30  .30  .35  .25  .30  .45  .25  .20  .30  .20
MOVEMENT (GRID) 1.45 1.25 1.25  .50 1.00  .75 1.10  .60  .35  .55
DIAMETER (GRID)  .25  .30  .20  .20  .15  .25  .50  .55  .55  .25
MOVEMENT (GRID)  .30  .40  .30  .25 1.05 1.10 1.00 1.05 1.25  .50
DIAMETER (GRID)  .20  .25  .70  .25
MOVEMENT (GRID)  .50 1.15 1.40  .50

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 28.
DIAMETER (GRID)  .30  .20  .30  .50  .60  .55  .35  .25  .50  .60
MOVEMENT (GRID)  .15  .10  .50  .75  .80 1.00  .55  .50  .40 1.10
DIAMETER (GRID)  .25  .40  .40  .55  .60  .20  .15  .15
MOVEMENT (GRID)  .35  .90  .75  .40 1.00  .15  .25  .10

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 29.
DIAMETER (GRID)  .50  .40  .55  .40  .70 1.20  .20  .40  .25  .65
MOVEMENT (GRID) 1.20 1.10 1.35 1.25 1.40 1.35  .45  .75  .35 1.60
DIAMETER (GRID)  .40
MOVEMENT (GRID) 1.00

    SAMPLING DISTANCE =  4.0         NEGATIVE NUMBER = 30.
DIAMETER (GRID)  .20  .25  .20  .20  .30  .50  .25  .25  .20  .25
MOVEMENT (GRID)  .45  .45  .35  .25  .70 1.00  .35  .30  .40  .55
DIAMETER (GRID)  .25  .20  .15  .25  .35  .25  .25  .25  .25  .35
MOVEMENT (GRID)  .20  .40  .30  .20  .55  .35  .45  .50  .55  .35
DIAMETER (GRID)  .20  .20  .25  .25  .50  .25  .25  .25  .35  .25
MOVEMENT (GRID)  .40  .30  .60  .75  .90  .30  .40  .15  .65  .35
DIAMETER (GRID)  .45
MOVEMENT (GRID)  .65
```

APPENDIX C CONTINUED

```
                   SAMPLING LOCATION DATA

                   DIESEL OIL AT 20 PSI
                   GRID CHART = 20 MM PER GRID UNIT
                   COMPARATOR MAG. = 10
                   CAMERA MAG. =  8.
                   FLASH DELAY = 25 MICROSECONDS

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 31.
DIAMETER (GRID)  .55  .20  .30  .25  .20  .40  .25  .20  .25  .25
MOVEMENT (GRID)  .60  .40  .90  .40  .20  .25 1.10  .35  .85  .20
DIAMETER (GRID)  .20  .45  .25  .30  .25  .40  .25  .15  .25  .30
MOVEMENT (GRID)  .40 1.10  .65  .80  .30 1.10  .20  .30  .35  .15
DIAMETER (GRID)  .25
MOVEMENT (GRID)  .25

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 32.
DIAMETER (GRID)  .25  .25  .20  .45  .40  .30  .50  .35  .60
MOVEMENT (GRID)  .40  .55  .40  .60  .55 1.65  .90  .45  .95

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 33.
DIAMETER (GRID)  .20  .25  .25  .35  .25  .30  .35  .40  .45  .95
MOVEMENT (GRID)  .30  .45  .35  .40  .20  .55  .90  .60  .65 1.10
DIAMETER (GRID)  .30  .70  .50  .30  .50
MOVEMENT (GRID)  .25 1.25 1.00  .55  .75

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 34.
DIAMETER (GRID)  .55  .20  .25  .20  .40 4.00  .55  .25
MOVEMENT (GRID)  .95  .50 1.05  .30 1.15 1.10 1.10  .50

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 35.
DIAMETER (GRID)  .70  .35  .25  .20  .20  .25  .10  .15  .25  .25
MOVEMENT (GRID)  .95  .70  .65  .85  .45  .40  .55  .45  .45  .40
DIAMETER (GRID)  .25  .30  .25  .20  .20  .75
MOVEMENT (GRID)  .45  .50  .40  .45  .40 1.30

    SAMPLING DISTANCE =  5.0          NEGATIVE NUMBER = 36.
DIAMETER (GRID)  .30  .70  .45  .25  .35  .60  .60  .45
MOVEMENT (GRID)  .45  .80  .85  .45  .45 1.05 1.00  .65
```

APPENDIX D

SAMPLE REPLICATION DATA (GRID READING DIAMETER)

Explanation of Tables

The numbers appearing in the following tables are the measurements of drop diameters taken from the optical comparator grid chart. These numbers can be converted into actual size using the following formula:

$$\text{Actual Size (mm)} = (\text{Grid Chart Reading})\frac{(\text{Grid Chart Constant mm/grid unit})}{(\text{Camera Mag.})(\text{Comparator Mag.})}$$

APPENDIX D

```
        SAMPLE REPLICATION DATA (GRID READING DIAMETER)

                DELAVAN FS-2-65 FAN NOZZLE
                WATER AT 40 PSI
                SAMPLING DISTANCE = 4.25 INCHES
                GRID CHART = 20 MM PER GRID UNIT
                CAMERA MAG = 10
                COMPARATOR MAG = 10

NEGATIVE NUMBER  2.
   .30   .55   .25   .10   .30   .30   .40   .20   .15   .20
   .20   .30   .30   .30   .45   .30   .15   .15   .35   .30

NEGATIVE NUMBER  3.
   .15   .25   .30   .25   .40   .15   .15   .65   .20   .25
   .15   .20   .85   .15   .20   .70

NEGATIVE NUMBER  4.
   .10   .10   .10   .15   .05   .10   .10   .15   .10   .10
   .15   .35   .10   .45   .15   .20   .10   .75   .20   .10
   .15   .10   .10   .65   .20   .10   .10   .10   .10   .15
   .15   .25   .15   .10   .60   .10   .10   .05   .10   .90
   .15   .15   .10

NEGATIVE NUMBER  7.
   .25   .75   .15   .25   .25   .25   .10   .20   .35   .30
   .20   .20   .20   .20   .30   .20   .20   .90

NEGATIVE NUMBER  8.
   .10   .10   .15   .20   .20   .10   .15   .20   .10   .10
   .10   .10   .05   .10   .10   .10   .25   .20   .05   .40
   .10   .15   .95   .20   .15   .20   .20   .10   .10   .50
   .10   .15   .10   .10   .75   .05   .10   .15   .10   .05
   .05   .15   .10   .05   .10   .10   .10   .50   .10   .10
   .10   .10

NEGATIVE NUMBER  9.
   .10   .10   .25   .15   .05   .10   .20   .10   .05   .10
   .15   .40   .10   .35   .15   .30   .20   .15   .80   .15
   .45   .20   .75   .25

NEGATIVE NUMBER 13.
   .20   .30   .20   .15   .10   .10   .25   .65   .35   .25
   .25   .30

NEGATIVE NUMBER 14.
   .45   .55   .20   .25   .40   .80   .15   .25   .70   .15
   .25   .20

NEGATIVE NUMBER 17.
   .90   .10   .20   .10   .10   .40   .10   .20   .10   .10
   .15   .35   .20   .10   .10   .10   .10   .25   .25   .10
```

APPENDIX D CONTINUED

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   .10    .20    .10    .10    .10    .10    .15    .15    .55    .15
   .20    .20    .15    .25    .10    .10    .20    .15

NEGATIVE NUMBER 18.
   .20    .20    .15    .10    .25    .65    .25    .60    .20    .20
   .15

NEGATIVE NUMBER 19.
   .40    .30    .25    .45    .25    .20    .50

NEGATIVE NUMBER 21.
   .60    .25    .20    .15    .10    .50

NEGATIVE NUMBER 22.
   .80    .10    .30    .20    .30    .30    .20    .60

NEGATIVE NUMBER 23.
   .30    .20    .60    .10    .30    .25    .35    .25    .15    .55
   .30    .10    .25    .25    .40

NEGATIVE NUMBER 24.
   .20    .10    .30    .25    .20    .70    .75    .35    .20    .55
   .20    .60    .10    .30    .15
```

APPENDIX D CONTINUED

SAMPLE REPLICATION DATA (GRID READING DIAMETER)

DELAVAN FS-2-65 FAN NOZZLE
DIESEL OIL AT 20 PSI
SAMPLING DISTANCE = 4.0 INCHES
GRID CHART = 20 MM PER GRID UNIT
CAMERA MAG = 8
COMPARATOR MAG = 10

NEGATIVE NUMBER 1.
.25 .25 .30 .25 .15 .15 .20 .30 .25 .30
.20 .25 .25 .25 .20 .25 .55 .30 .25 .30
.25 .25 .15 .35 .15 .10 .20 .10 .20 .15
.45 .25 .20 .15 .15 .15 .20 .15 .20 .15
.10 .20 .10 .40 .30 .25 .20 .25 .20 .25
.20 .10 .50 .20 .25 .20

NEGATIVE NUMBER 2.
.15 .20 .15 .10 .20 .20 .15 .25 .25 .20
.30 .25 .30 .15 .20 .10 .20 .50 .10 .15
.20 .20 .20 .15 .20 .20 .15 .30 .25 .50
.50 .25 .20 .10 .20 .25 .25 .15 .45 .20
.20 .20 .20 .65 .25 .25 .30 .20 .10

NEGATIVE NUMBER 3.
.20 .20 .15 .15 .25 .20 .30 .15 .15 .40
.20 .20 .20 .25 .15 .25 .10 .15 .15 .15
.15 .10 .10 .20 .10 .15 .25 .20 .25 .25
.10 .15 .20 .35 .15 .15 .30 .25 .25 .20
.20 .25 .25 .15 .20 .15 .25

NEGATIVE NUMBER 5.
.15 .25 .10 .20 .15 .25 .15 .35 .35 .20
.30 .20 .25 .20 .25 .25 .25 .20 .25 .20
.20 .10 .15 .20 .25 .20 .20 .15 .15 .20
.15 .65

NEGATIVE NUMBER 6.
.15 .40 .25 .25 .10 .30 .25 .10 .10 .10
.15 .15 .10 .10 .20 .20 .15 .25 .25 .25
.20 .15 .10 .25 .15 .15 .15 .20 .25 .20
.20 .25 .20 .45 .20 .15 .15 .20 .25 .15
.15 .20 .10 .25 .20 .20 .25 .25 .10 .25
.20 .25 .20

NEGATIVE NUMBER 7.
.25 .30 .10 .25 .15 .25 .20 .20 .25 .15
.10 .25 .25 .20 .20 .20 .15 .25 .25 .15
.25 .10 .25 .10 .15 .19 .15 .25 .10 .25
.25 .25 .20 .20 .45

NEGATIVE NUMBER 8.
.30 .25 .25 .25 .30 .10 .25 .50 .20 .15
.20 .40 .10 .10 .15 .60 .20 .10 .30 .15

APPENDIX D CONTINUED

```
   .15   .15   .10   .15   .25   .55

NEGATIVE NUMBER 10.
   .30   .35   .25   .40   .15   .15   .30   .25   .15   .25
   .15   .10   .40   .10   .20   .45   .25   .25   .25   .20
   .25   .15   .25   .35   .15   .15   .15   .15   .10   .15
   .15   .15   .10   .15   .10   .15   .20   .15   .20   .10
   .20

NEGATIVE NUMBER 11.
   .20   .25   .20   .75   .15   .15   .15   .20   .25   .25
   .25   .25   .60   .30   .10   .30   .15   .25   .15   .25
   .10   .35   .35   .25   .15   .45   .15   .10   .20   .15
   .25   .20   .15   .15   .25   .15

NEGATIVE NUMBER 12.
   .15   .25   .20   .10   .15   .25   .20   .70   .40   .25
   .65   .15   .15   .50   .25   .20   .20   .20   .10   .20
   .30   .25   .25   .25   .25   .30   .20   .15   .10   .20
   .30   .25   .25   .25   .10   .10   .45   .35   .20   .20
   .55   .25   .15

NEGATIVE NUMBER 14.
   .20   .25   .25   .20   .25   .20   .20   .15   .70   .25
   .30   .20   .10   .25   .50   .30   .30   .25   .20   .20
   .10   .25   .20   .15   .15   .25   .20   .25   .20   .20
   .40   .25   .25   .30

NEGATIVE NUMBER 16.
   .25   .20   .15   .15   .15   .15   .25   .20   .20   .15
   .15   .45   .20   .20   .15   .15   .55   .20   .25   .20
   .15   .15   .20   .10   .15   .15   .15   .10   .15   .20
   .15   .15   .10   .15   .10   .15   .20   .15   .15   .25
   .10   .20

NEGATIVE NUMBER 17.
   .50   .25   .15   .15   .10   .10   .20   .15   .75   .20
   .50   .10   .15   .15   .20   .35   .15   .25   .10   .15
   .20   .25   .15   .20   .25   .10   .15   .20   .30   .30
   .15   .20   .25   .20   .15   .20   .25   .10   .15   .20
   .20   .20   .45   .10   .20   .20   .45   .20

NEGATIVE NUMBER 18.
   .30   .10   .25   .20   .35   .15   .20   .15   .20   .30
   .15   .25   .30   .25   .80   .50   .25   .70   .10   .25
   .20   .15   .20   .25   .25   .20   .25   .20   .20   .20
   .25   .25   .20   .25   .15   .15   .25   .15   .30   .40
   .40   .20   .20   .25   .45   .25   .40
```

APPENDIX D CONTINUED

SAMPLE REPLICATION DATA (GRID READING DIAMETERS)

```
                    DELAVAN CS-1 (WITH CORE REMOVED)
                    ORIFICE DIAMETER = 250 MICRONS
                    WATER AT 3 PSI
                    SAMPLING DISTANCE = 2.25 INCHES
                    GRID CHART = 20 MM PER GRID UNIT
                    CAMERA MAG = 8
                    COMPARATOR MAG = 10


   NEGATIVE NUMBER  1.
MAJOR DIA LARGE 2.90 2.35 2.35 2.10 2.45 2.95 2.65 2.70 2.30
MINOR DIA LARGE 2.05 2.10 2.10 2.00 1.80 1.90 1.95 1.85 2.00

   NEGATIVE NUMBER  2.
MAJOR DIA LARGE 3.25 2.55 2.00 2.20 2.15 2.40 2.60 2.90
MINOR DIA LARGE 2.50 2.20 1.75 2.00 2.00 1.85 2.30 1.75

   NEGATIVE NUMBER  3.
MAJOR DIA LARGE 2.40 2.70 2.40 2.05 2.15 2.35 2.40 3.10
MINOR DIA LARGE 2.15 2.40 2.15 1.90 2.00 2.00 1.75 2.60
DIAMETER SMALL   .85

   NEGATIVE NUMBER  4.
MAJOR DIA LARGE 3.50 2.50 2.35 2.65 2.90 2.40 2.75 2.85
MINOR DIA LARGE 2.05 1.85 2.00 1.90 1.50 2.15 1.85 2.05
DIAMETER SMALL   .80  .85

   NEGATIVE NUMBER  5.
MAJOR DIA LARGE 2.75 3.30 2.35 4.35 2.15 3.05 2.40 2.15
MINOR DIA LARGE 1.75 2.15 2.00 2.75 2.00 2.00 2.00 2.00
DIAMETER SMALL   .50

   NEGATIVE NUMBER  6.
MAJOR DIA LARGE 2.75 2.50 2.80 2.30 2.40 2.20 2.30 2.55 2.55
MINOR DIA LARGE 2.20 1.85 2.10 2.00 1.80 2.00 2.10 2.25 1.85
DIAMETER SMALL   .55  .60

   NEGATIVE NUMBER  7.
MAJOR DIA LARGE 2.80 2.45 2.25 2.45 2.30 3.10 2.55
MINOR DIA LARGE 2.30 2.40 1.75 1.90 1.85 2.00 2.15
DIAMETER SMALL   .65  .50

   NEGATIVE NUMBER  8.
MAJOR DIA LARGE 2.60 2.25 2.40 2.45 2.85 2.65 2.75 2.60
MINOR DIA LARGE 1.90 1.95 2.00 1.85 2.20 1.95 1.85 1.95
```

APPENDIX E

SAMPLING PATTERN DATA (GRID READING DIAMETERS)

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

Explanation of Tables

The numbers appearing in the tables of Appendix E-I are the measurements of drop diameters taken from the optical comparator grid chart. These numbers can be converted into actual size using the following formula:

$$\text{Actual Size (mm)} = (\text{Grid Chart Reading}) \frac{(\text{Grid Chart Constant mm/grid unit})}{(\text{Camera Mag.})(\text{Comparator Mag.})}$$

APPENDIX E-I

```
                                    SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                          DELAVAN FS-2-65 FAN NOZZLE
                                          WATER AT 40 PSI
                                          SAMPLING DISTANCE = 6 INCHES
                                          GRID CHART = 20 MM PER GRID UNIT
                                          CAMERA MAG = 8
                                          COMPARATOR MAG = 10
      SAMPLING POSITION NO.  1.     REP. NO. 1.
.15   .55   .30   .30   .30   .20   .20   .25   .30   .20   .45   .25   .50   .15   .30   .30   .30   .10   .10   .30
.45   .40   .25   .40  1.20   .20   .15
      SAMPLING POSITION NO.  2.     REP. NO. 1.
.15   .25   .20   .15   .30   .30   .20   .50   .25   .45   .60   .25   .10   .15   .15   .40   .45   .35   .40   .25
.30   .30   .25   .25
      SAMPLING POSITION NO.  3.     REP. NO. 1.
.60   .35   .25   .40   .20   .25   .20   .30   .65   .15   .25   .10   .20   .40   .35   .60   .20   .20   .35   .55
.35   .40   .20   .10   .35   .25
      SAMPLING POSITION NO.  4.     REP. NO. 1.
.45   .35   .30   .25   .10   .10   .25   .20   .15   .25   .15   .25   .40   .70   .25   .25   .25   .25   .45   .20
.30   .20   .25   .15   .15   .15   .25
      SAMPLING POSITION NO.  5.     REP. NO. 1.
.25   .25   .20   .30   .15   .20   .30   .25   .25   .20   .20   .20   .25   .20   .45   .15   .25   .40   .20   .30
.20   .35   .25   .20   .35   .30   .25   .35   .20   .25
      SAMPLING POSITION NO.  6.     REP. NO. 1.
.40   .30   .25   .35   .25   .25   .10   .55   .55   .15   .70   .40   .25   .40
      SAMPLING POSITION NO.  7.     REP. NO. 1.
.35   .25   .40   .35   .40   .55   .20  1.00   .40   .15  1.00   .15
      SAMPLING POSITION NO.  8.     REP. NO. 1.
.15   .25   .25   .15   .20   .15   .20   .30   .25   .15   .10   .15   .25   .45   .40   .20   .25   .15   .25   .20
.25   .30   .25   .20   .25   .20   .15   .40   .25   .20   .70   .15   .30   .15   .35   .15
      SAMPLING POSITION NO.  9.     REP. NO. 1.
.30   .35   .80   .35   .15   .15   .10   .15   .10   .15   .25   .15   .25   .25   .20   .40   .20   .15   .20   .15
.25   .35   .10   .15   .15   .15   .20   .20   .25   .35   .25   .15   .15   .15   .15   .25   .15   .25   .30
      SAMPLING POSITION NO. 10.     REP. NO. 1.
.45   .25   .15   .30   .15   .40   .20   .85   .15   .25   .30   .40   .15   .20   .55   .15   .25   .25   .15   .25
.20

      SAMPLING POSITION NO. 11.     REP. NO. 1.
.35   .25   .10   .15   .10   .35   .55   .20   .15   .25   .20   .15   .60   .25   .20   .30   .20   .25   .25   .20
.20   .25   .20   .35   .25   .25   .25   .30   .50   .20
      SAMPLING POSITION NO. 12.     REP. NO. 1.
.35   .35   .35   .15   .20   .25   .20   .30   .35   .30   .30   .20   .30   .20   .25   .15   .15   .25   .45   .20
.25   .15   .35   .30   .20   .35   .15   .30   .25   .15   .35
      SAMPLING POSITION NO. 13.     REP. NO. 1.
.80   .30   .45   .35   .55   .45   .10   .40   .25   .15   .30   .50   .30   .20
      SAMPLING POSITION NO. 14.     REP. NO. 1.
.35   .20   .10   .80   .10   .15
      SAMPLING POSITION NO. 15.     REP. NO. 1.
.30   .25   .35   .25   .30   .25   .40   .45   .15   .20   .25   .40   .40   .25   .20   .15   .20   .10
      SAMPLING POSITION NO. 16.     REP. NO. 1.
.25   .25   .35   .30   .45   .45   .45   .15   .35   .15   .15
      SAMPLING POSITION NO. 17.     REP. NO. 1.
.50   .35   .40   .25   .45   .15   .35   .20   .35   .45   .25   .15   .35
      SAMPLING POSITION NO. 18.     REP. NO. 1.
.40   .15   .30   .45   .40   .45   .40  1.05   .45   .75   .40   .30   .35
      SAMPLING POSITION NO. 19.     REP. NO. 1.
.50   .40   .45   .55   .25   .30   .10   .85   .15   .30
```

APPENDIX E-I CONTINUED

```
     SAMPLING POSITION NO. 20.       REP. NO. 1.
.15   .45   .45   .45   .20   .25   .45   .65   .35   .30
     SAMPLING POSITION NO. 21.       REP. NO. 1.
.10   .10   .15   .20
     SAMPLING POSITION NO. 22.       REP. NO. 1.
.35   .20   .30   .20   .30   .20   .30   .10   .25   .70   .15   .15   .55   .50   .55   .35   .30
     SAMPLING POSITION NO. 23.       REP. NO. 1.
.15   .15   .35   .40   .25   .10
     SAMPLING POSITION NO. 24.       REP. NO. 1.
.40   .35   .10   .35   .15   .35   .10
     SAMPLING POSITION NO. 25.       REP. NO. 1.
.40   .30   .45   .15   .35   .40   .25   .25   .35
     SAMPLING POSITION NO. 26.       REP. NO. 1.
.50   .50   .10
     SAMPLING POSITION NO. 27.       REP. NO. 1.
.45   .15   .55   .15   .15
     SAMPLING POSITION NO. 28.       REP. NO. 1.
.55   .95   .25
     SAMPLING POSITION NO. 29.       REP. NO. 1.
.40   .10   .10   .45   .40   .15   .10   .30   .25
     SAMPLING POSITION NO. 30.       REP. NO. 1.
.20   .15   .40
     SAMPLING POSITION NO. 31.       REP. NO. 1.
.15   .15
     SAMPLING POSITION NO. 32.       REP. NO. 1.
.15
```

APPENDIX E-I CONTINUED

```
                                     SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                           DELAVAN FS-2-65 FAN NOZZLE
                                           WATER AT 40 PSI
                                           SAMPLING DISTANCE = 6 INCHES
                                           GRID CHART = 20 MM PER GRID UNIT
                                           CAMERA MAG = 8
                                           COMPARATOR MAG = 10
     SAMPLING POSITION NO.  1.       REP. NO. 2.
.25   .30   .40   .15   .35   .10   .25   .30   .25   .30   .30   .30   .20   .40   .35   .40   .30   .60   .25   .40
.35   .25   .20   .35   .15   .25   .25   .15   .30   .25   .20   .75   .30   .20   .30   .15
     SAMPLING POSITION NO.  2.       REP. NO. 2.
.15   .15   .30   .15   .10   .10   .25   .15   .20   .20   .15   .10   .20   .15   .20   .15   .15   .10   .10   .15
.20   .35   .15   .35   .15   .25   .30   .30   .35   .20
     SAMPLING POSITION NO.  3.       REP. NO. 2.
.25   .20   .20   .25   .15   .20   .20   .20   .20   .25   .15   .25   .25   .30   .30   .30   .20   .15   .15   .30
.25   .15   .25   .25   .25   .35   .15
     SAMPLING POSITION NO.  4.       REP. NO. 2.
.10   .95   .45   .65   .80   .25   .25   .45   .65   .30   .25   .30   .30   .10   .10   .10   .15   .15   .20   .25
.10   .20
     SAMPLING POSITION NO.  5.       REP. NO. 2.
.40   .30   .40   .10   .60   .35   .25   .90   .15   .20   .25
     SAMPLING POSITION NO.  6.       REP. NO. 2.
.45   .30  1.00   .10   .50   .50   .30   .30   .25   .25   .55   .40   .10   .20   .25
     SAMPLING POSITION NO.  7.       REP. NO. 2.
.40   .30   .25   .35   .40   .55   .20   .25   .40   .10   .30   .50   .30   .35   .30   .35
     SAMPLING POSITION NO.  8.       REP. NO. 2.
.15   .15   .15   .35   .20   .20   .20   .10   .25   .20   .25   .15   .40   .35   .15   .35   .30   .35   .30   .30
.35   .25   .20   .15   .15
     SAMPLING POSITION NO.  9.       REP. NO. 2.
.30   .35   .30   .60   .40   .75   .10   .20   .40   .45   .15   .25   .15   .30   .30   .25   .10   .10   .30   .20
.25
     SAMPLING POSITION NO. 10.       REP. NO. 2.
.50   .45   .15   .40   .45   .40   .35   .40   .30   .45   .35   .50   .40   .35
     SAMPLING POSITION NO. 11.       REP. NO. 2.
.45   .30   .90   .30   .40   .30   .20   .20   .15   .35   .20   .25   .15   .20   .25   .30   .55   .10   .15   .35
.20   .25
     SAMPLING POSITION NO. 12.       REP. NO. 2.
.40   .50   .45   .30   .45   .30  1.30   .45   .10   .45   .40   .35   .40   .45
     SAMPLING POSITION NO. 13.       REP. NO. 2.
.10   .75   .45   .55   .35   .30   .55
     SAMPLING POSITION NO. 14.       REP. NO. 2.
.40   .30   .30   .45   .50
     SAMPLING POSITION NO. 15.       REP. NO. 2.
.25   .25   .30   .25   .50   .35   .25   .30   .35   .50   .40   .15
     SAMPLING POSITION NO. 16.       REP. NO. 2.
.15   .25   .30   .25   .30   .20   .35   .35   .10   .40   .50   .20   .20   .15   .10   .20   .20   .20
     SAMPLING POSITION NO. 17.       REP. NO. 2.
.25   .40   .40   .15
     SAMPLING POSITION NO. 18.       REP. NO. 2.
.20   .45   .10   .40   .15   .10   .10   .20
     SAMPLING POSITION NO. 19.       REP. NO. 2.

     SAMPLING POSITION NO. 20.       REP. NO. 2.
.60   .20
     SAMPLING POSITION NO. 21.       REP. NO. 2.
```

APPENDIX E-I CONTINUED

```
      SAMPLING POSITION NO. 22.       REP. NO. 2.
 .10   .55   .10   .25   .25
      SAMPLING POSITION NO. 23.       REP. NO. 2.
 .35
      SAMPLING POSITION NO. 24.       REP. NO. 2.
 .40   .25   .25   .40
      SAMPLING POSITION NO. 25.       REP. NO. 2.
1.00
      SAMPLING POSITION NO. 26.       REP. NO. 2.
 .50   .40
      SAMPLING POSITION NO. 27.       REP. NO. 2.
 .40   .20
      SAMPLING POSITION NO. 28.       REP. NO. 2.

      SAMPLING POSITION NO. 29.       REP. NO. 2.
 .50
      SAMPLING POSITION NO. 30.       REP. NO. 2.
 .50
      SAMPLING POSITION NO. 31.       REP. NO. 2.

      SAMPLING POSITION NO. 32.       REP. NO. 2.
 .45
```

APPENDIX E-I   CONTINUED

```
                                    SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                        DELAVAN FS-2-65 FAN NOZZLE
                                        WATER AT 40 PSI
                                        SAMPLING DISTANCE = 6 INCHES
                                        GRID CHART = 20 MM PER GRID UNIT
                                        CAMERA MAG = 8
                                        COMPARATOR MAG = 10
     SAMPLING POSITION NO.  1.      REP. NO. 3.
.10   .35   .15   .20   .20   .20   .15   .25   .30   .10   .25
     SAMPLING POSITION NO.  2.      REP. NO. 3.
.50   .10   .10   .30   .50   .05   .15   .35   .10   .20   .40   .20   .10   .30   .15   .20   .65
     SAMPLING POSITION NO.  3.      REP. NO. 3.
.20   .20   .10   .35   .20   .10   .35   .20   .10   .25   .30   .20   .25   .25   .10   .15
     SAMPLING POSITION NO.  4.      REP. NO. 3.
.50   .10   .50   .25   .10   .25   .25   .25   .20   .10   .25   .30   .10   .40   .25   .15   .30   .35   .30   .30
.25
     SAMPLING POSITION NO.  5.      REP. NO. 3.
.30   .20   .50   .40   .15   .20   .35   .30   .20
     SAMPLING POSITION NO.  6.      REP. NO. 3.
.10   .35   .40   .35   .50   .10
     SAMPLING POSITION NO.  7.      REP. NO. 3.
.35   .30   .30   .45   .45
     SAMPLING POSITION NO.  8.      REP. NO. 3.
1.00  .10
     SAMPLING POSITION NO.  9.      REP. NO. 3.
.10   .05   .10   .35   .45   .10   .30   .05   .50   .30   .10
     SAMPLING POSITION NO. 10.      REP. NO. 3.
.30   .35   .30   .10   .30   .35
     SAMPLING POSITION NO. 11.      REP. NO. 3.
.25   .20   .30   .20   .20   .10   .10   .30   .10   .15   .30   .30
     SAMPLING POSITION NO. 12.      REP. NO. 3.
.35   .30   .40   .35   .45   .20
     SAMPLING POSITION NO. 13.      REP. NO. 3.
.55   .50   .35
     SAMPLING POSITION NO. 14.      REP. NO. 3.
.65   .20   .40   .20
     SAMPLING POSITION NO. 15.      REP. NO. 3.
.45   .20   .20   .10
     SAMPLING POSITION NO. 16.      REP. NO. 3.
.25   .20   .25   .40   .55   .10   .10   .20   .40   .25
     SAMPLING POSITION NO. 17.      REP. NO. 3.
.05   .40   .20   .35   .10   .30   .30   .35   .15   .35
     SAMPLING POSITION NO. 18.      REP. NO. 3.
.10   .10   .05   .10   .40   .10
     SAMPLING POSITION NO. 19.      REP. NO. 3.
.10   .30   .25   .10   .25   .10   .65   .65   .10   .05
     SAMPLING POSITION NO. 20.      REP. NO. 3.

     SAMPLING POSITION NO. 21.      REP. NO. 3.
.40   .15
     SAMPLING POSITION NO. 22.      REP. NO. 3.
.40   .50
     SAMPLING POSITION NO. 23.      REP. NO. 3.
.10   .15   .30   .10   .15   .10   .10   .15   .10   .15   .05   .15   .10   .05   .35
     SAMPLING POSITION NO. 24.      REP. NO. 3.
.20   .40   .35   .45   .95   .55   .40
```

APPENDIX E-I CONTINUED

```
     SAMPLING POSITION NO. 25.       REP. NO. 3.
.35   .50   .40
     SAMPLING POSITION NO. 26.       REP. NO. 3.
.75   .45   .30
     SAMPLING POSITION NO. 27.       REP. NO. 3.
.50
     SAMPLING POSITION NO. 28.       REP. NO. 3.
.40
     SAMPLING POSITION NO. 29.       REP. NO. 3.
.25   .20
     SAMPLING POSITION NO. 30.       REP. NO. 3.
.40   .50   .25   .15   .25   .15   .25
     SAMPLING POSITION NO. 31.       REP. NO. 3.

     SAMPLING POSITION NO. 32.       REP. NO. 3.
.40   .10   .45
```

APPENDIX E-I   CONTINUED

```
                                    SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                          DELAVAN FS-2-65 FAN NOZZLE
                                          WATER AT 40 PSI
                                          SAMPLING DISTANCE = 6 INCHES
                                          GRID CHART = 20 MM PER GRID UNIT
                                          CAMERA MAG = 8
                                          COMPARATOR MAG = 10
     SAMPLING POSITION NO.  1.      REP. NO. 4.
.10   .25   .40   .25   .40   .35   .20   .25   .15   .15   .10   .25   .15   .20   .15   .15   .10   .20   .25   .25
.10   .25   .15   .10
     SAMPLING POSITION NO.  2.      REP. NO. 4.
.15   .15   .20   .20
     SAMPLING POSITION NO.  3.      REP. NO. 4.
.50   .20  1.00   .10   .35   .30   .25   .25   .10   .30
     SAMPLING POSITION NO.  4.      REP. NO. 4.
.25   .30   .20   .20   .35   .25   .25   .30   .25   .25   .30   .15   .30   .30
     SAMPLING POSITION NO.  5.      REP. NO. 4.
.40   .50   .40   .50   .40   .25   .50   .40
     SAMPLING POSITION NO.  6.      REP. NO. 4.
.25   .15   .25   .30   .35   .80   .35
     SAMPLING POSITION NO.  7.      REP. NO. 4.
.40   .75
     SAMPLING POSITION NO.  8.      REP. NO. 4.
.30   .25   .60   .35   .25   .35   .40   .20
     SAMPLING POSITION NO.  9.      REP. NO. 4.
.25   .25   .15   .10   .10   .20   .25   .15   .15   .20   .50   .15   .50   .35   .55   .35   .25   .25   .30   .25
.25
     SAMPLING POSITION NO. 10.      REP. NO. 4.
.30   .15   .35   .25   .35   .30   .15   .45   .35   .10   .30   .40   .30   .30   .25
     SAMPLING POSITION NO. 11.      REP. NO. 4.
.15   .15   .25   .35   .25   .25   .25   .30   .45   .40   .15   .50   .30   .75   .65   .80
     SAMPLING POSITION NO. 12.      REP. NO. 4.
.25   .30   .20   .10   .20   .25
     SAMPLING POSITION NO. 13.      REP. NO. 4.
.45   .40   .65   .45
     SAMPLING POSITION NO. 14.      REP. NO. 4.
.95   .20   .40   .20
     SAMPLING POSITION NO. 15.      REP. NO. 4.
.15   .35   .25   .30   .35   .40   .25   .30   .20   .55
     SAMPLING POSITION NO. 16.      REP. NO. 4.
.15   .30   .15   .15   .10   .45   .25   .10   .15   .35   .15   .10
     SAMPLING POSITION NO. 17.      REP. NO. 4.
.25   .30   .40
     SAMPLING POSITION NO. 18.      REP. NO. 4.
.20   .35   .35   .10   .10   .15   .40   .25
     SAMPLING POSITION NO. 19.      REP. NO. 4.
.20   .15   .25   .10   .40   .30   .70   .40   .35   .40   .25
     SAMPLING POSITION NO. 20.      REP. NO. 4.
.40   .45   .35
     SAMPLING POSITION NO. 21.      REP. NO. 4.
.35   .35   .30
     SAMPLING POSITION NO. 22.      REP. NO. 4.
.60
     SAMPLING POSITION NO. 23.      REP. NO. 4.
.70   .30   .40   .40   .25
```

APPENDIX E-I   CONTINUED

```
     SAMPLING POSITION NO. 24.      REP. NO. 4.
.10   .35   .20   .20   .40   .30   .30   .35
     SAMPLING POSITION NO. 25.      REP. NO. 4.
.45
     SAMPLING POSITION NO. 26.      REP. NO. 4.
.25   .30   .45   .35
     SAMPLING POSITION NO. 27.      REP. NO. 4.
.35   .45
     SAMPLING POSITION NO. 28.      REP. NO. 4.

     SAMPLING POSITION NO. 29.      REP. NO. 4.
.10   .40   .35   .10   .20   .50
     SAMPLING POSITION NO. 30.      REP. NO. 4.
.25   .60   .25   .60
     SAMPLING POSITION NO. 31.      REP. NO. 4.
.60   .95   .50   .45
     SAMPLING POSITION NO. 32.      REP. NO. 4.
.20   .30
```

APPENDIX E-I CONTINUED

```
                                       SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                             DELAVAN FS-2-65 FAN NOZZLE
                                             DIESEL FUEL AT 20 PSI
                                             SAMPLING DISTANCE = 4 INCHES
                                             GRID CHART = 20 MM PER GRID UNIT
                                             CAMERA MAG = 8
                                             COMPARATOR MAG = 10
       SAMPLING POSITION NO.  1.       REP. NO. 1.
   .15   .25   .25   .15   .10   .30   .15   .25   .10   .40   .20   .20   .25   .25   .35   .35   .15   .15   .15   .25
   .45   .10   .15   .10   .10   .10   .10   .25   .40   .25   .25   .20   .10   .10   .45   .40   .20   .20   .25   .15
   .35   .30   .10   .15   .25   .20   .25   .15   .15   .10   .10   .10   .20   .35   .25   .15   .10   .20   .25   .10
   .25   .20   .30   .40   .40   .40   .20   .20   .10   .10   .25   .30   .20   .25   .15   .20   .20   .15   .30   .15
   .15   .15   .05   .10   .10   .10   .10   .10   .15   .20   .35   .30   .10   .10   .10   .50   .10   .10   .25   .05
   .10   .20   .10  1.00   .10   .30   .10   .65   .30   .25   .25   .25   .10   .10   .25   .45   .25   .15   .15   .20
   .35   .20   .45   .50   .15   .20   .25   .10   .10   .10   .25   .15   .15   .25   .10   .05   .35   .20   .25   .50
   .25   .20   .10   .15   .60   .30   .15
       SAMPLING POSITION NO.  2.       REP. NO. 1.
   .30   .20   .20   .10   .25   .25   .40   .10   .15   .15   .25   .10   .15   .05   .15   .30   .25   .25   .30   .10
   .10   .35   .25   .20   .05   .05   .05   .05   .10   .05   .35   .10   .10   .10   .10   .20   .20   .25   .30   .10
   .20   .15   .20   .20   .30   .25   .15   .10   .10   .20   .10   .20   .15   .20   .30   .15   .15   .15   .15   .15
   .15   .15   .20   .25   .15   .10   .20   .10   .05   .10   .10   .05   .20   .35   .10   .20   .20   .25   .05   .10
   .35   .25   .25   .15   .30   .15   .05   .10   .15   .40   .30   .30   .25   .15   .15   .20   .40   .15   .25   .15
   .25   .30   .15   .15   .20   .15   .10   .25   .25   .10   .20   .20   .15   .30   .40   .05   .25   .25   .30   .20
   .20   .25   .10   .25   .40   .35   .10   .20   .35   .15   .10   .20   .15   .15   .10   .10   .20   .45   .35   .20
   .20   .10   .10   .15   .15   .15   .10   .20   .15   .10   .05   .20   .05   .10   .15   .25   .15   .15
       SAMPLING POSITION NO.  3.       REP. NO. 1.
   .10   .15   .25   .15   .15   .20   .25   .10   .15   .10   .10   .10   .10   .10   .20   .15   .05   .50   .10   .10
   .25   .10   .40   .40   .20   .25   .30   .15   .50   .30   .30   .85   .20   .30   .10   .15   .50   .10   .10   .35
   .50   .30   .25   .15   .30   .85   .25   .15   .15   .15   .10   .10   .50   .05   .05   .40   .40   .30   .25   .30
   .25   .35   .45   .20   .20   .10   .10   .10   .25   .30   .15   .15   .15   .10   .15   .10   .20   .60   .10   .15
   .15   .15   .20   .15   .10   .10   .15   .15   .75   .55   .60   .25   .20   .15   .25   .30   .80   .30   .10   .10
   .10   .25   .10   .10   .10
       SAMPLING POSITION NO.  4.       REP. NO. 1.
   .25   .05   .10   .10   .25   .25  1.40  1.70  1.10   .30   .25   .10   .10   .35   .55   .20   .30   .30   .15   .50
   .10   .25   .10   .45   .70   .35   .30   .30   .50   .25   .70   .45   .30   .30   .10   .10   .10   .10   .15   .25
   .30   .30   .35   .35   .05   .20   .20   .60   .25   .25   .25   .30   .15   .10   .35   .05   .20   .45   .20   .10
   .10   .10   .10   .15   .15   .65   .15   .20   .60   .40   .25   .15   .10   .15   .20   .10   .15   .15  1.65  1.75
  1.45  1.75  1.95
       SAMPLING POSITION NO.  5.       REP. NO. 1.
   .35   .25   .25   .35   .10   .25   .30   .35   .25   .25   .10   .35   .30   .10   .40   .25   .25   .50   .35   .35
   .35   .20   .10   .30   .30   .30   .60   .25   .05   .25   .35   .05   .10   .25
       SAMPLING POSITION NO.  6.       REP. NO. 1.
   .40   .25   .20   .15   .30   .25   .15   .25   .75   .55   .25   .60   .25   .30   .65   .20   .20   .40   .15   .25
   .25   .15   .15   .20   .25   .50   .40   .15   .20   .15   .20   .65   .25   .25   .25   .10   .20   .20   .10   .10
   .15   .20   .20   .25   .15   .15   .05   .10   .20   .05   .10   .10   .10   .10   .30   .50   .10   .15   .40   .15
   .10   .15   .15   .15   .10   .10   .10   .65   .15   .10   .10   .10   .10   .10   .15   .15   .25   .25   .20   .30
   .10   .05   .10   .10   .20  1.10   .15   .10   .10   .15   .15   .10   .05   .10   .15   .25   .15   .15   .15   .25
   .10   .25   .05   .15   .10   .10   .10   .10   .40   .50   .25   .25   .50   .40   .15   .25   .25   .25   .25   .45
   .60   .20   .25   .15   .25   .20   .25   .55   .15   .20   .15   .15   .15   .10   .15   .15   .15   .15   .10   .20
   .25   .15   .50   .45   .15   .20   .15   .60   .10   .20   .10   .15   .20
       SAMPLING POSITION NO.  7.       REP. NO. 1.
   .20   .25   .25   .25   .25   .15   .10   .10   .15   .10   .20   .10   .25   .35   .25   .10   .15   .15   .15   .20
   .25   .25   .20   .30   .25   .15   .10   .25   .15   .15   .20   .10   .10   .15   .20   .20   .10   .20   .10   .25
   .35   .10   .20   .35   .20   .15   .15   .25   .20   .45   .30   .20   .10   .10   .10   .15   .15   .20   .30   .35
   .20   .20   .35   .30   .20   .35   .30   .10   .15   .20   .15   .20   .25   .30   .15   .25   .30   .10   .10   .15
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APPENDIX E-I CONTINUED

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.60     .15     .25     .10     .15     .30     .20     .20     .25     .30     .10     .20     .10     .30     .20     .10     .10     .20     .20     .20
.10     .35     .25
        SAMPLING POSITION NO.  8.       REP. NO. 1.
.20     .50     .35     .20     .25     .20     .10     .20     .35     .25     .15     .20     .30     .25     .10     .15     .25     .35     .10     .20
.25     .25     .35     .50     .10     .15     .25     .15     .10     .20     .20     .40     .25     .50     .15     .15     .15     .35     .25     .10
.10     .25     .30     .25     .50     .25     .20     .50     .20     .25     .20     .10     .20     .25     .20     .25     .15     .35     .25     .25
.20     .10     .20     .20     .30     .10     .15     .25     .30     .30     .25     .25     .20     .15     .20     .25     .25     .45     .15     .25
.20     .25     .10     .25     .70     .25     .10     .25     .15     .20     .20     .20     .25     .15     .15     .45     .25     .20     .25     .25
        SAMPLING POSITION NO.  9.       REP. NO. 1.
.30     .25     .35     .25     .25     .25     .25     .20     .10     .25     .35     .30     .10     .20     .35     .25     .10     .10     .10     .40
.60     .25     .30     .50     .15     .35     .10     .35     .30     .25     .10     .25     .35     .25     .15     .30     .25     .35     .25     .35
.55     .40     .45     .45     .50     .30     .40     .35     .20     .45     .30     .35     .25     .40     .25     .25     .15     .34     .25     .35
.25     .35     .50     .10     .50     .50     .50     .25     .30     .45     .15     .50     .25     .10
        SAMPLING POSITION NO. 10.       REP. NO. 1.
.35     .10     .15     .25     .25     .30     .25     .15     .25     .10     .10     .10     .15     .45     .50     .30     .25     .35     .40     .35
.30     .25     .30     .35     .30
        SAMPLING POSITION NO. 11.       REP. NO. 1.
.15     .15     .10     .10     .10     .10     .20     .10     .10     .25     .30     .25     .25     .25     .10     .25     .15     .10     .25     .10
.15     .10     .30     .15     .20     .10     .15     .10     .10     .10     .10     .10     .15     .20     .50     .10     .15     .10     .10     .20
.20     .20     .10     .20     .10     .25     .20     .20     .20     .30     .10     .10     .10     .10     .10     .15     .10     .25     .10     .10
.10     .10     .10     .10     .15     .10     .20     .10     .20     .10     .10     .25     .10     .10     .10     .25     .15     .30     .20     .40
.20     .10     .20     .25     .25     .10     .15     .35     .10     .55     .15     .40     .25     .15     .35     .10     .20     .30     .30     .25
.10     .10     .10     .20     .20     .25     .20     .20     .15     .20     .15     .10     .25     .30     .15     .25     .25     .15     .15     .10
.15     .15     .30     .10     .15     .25     .10     .10     .10     .35     .25     .30     .10     .15     .10     .10     .15     .20     .10     .10
.10     .10     .10     .15     .15     .10     .15
        SAMPLING POSITION NO. 12.       REP. NO. 1.
.45     .10     .10     .25     .10     .20     .10     .15     .10     .10     .10     .25     .15     .15     .20     .40     .70     .15     .15     .10
.30     .25     .20     .20     .20     .15     .20     .10     .25     .10     .25     .20     .20     .40     .20     .30     .50     .20     .15     .15
.25     .30     .15     .15     .10     .15     .10     .10     .15     .20     .25     .20     .45     .50     .15     .20     .15     .10     .10     .10
.15     .10     .15     .30     .15     .20     .10     .20     .15     .20     .15     .10     .15     .10     .10     .20     .15     .25     .10     .25
.10     .20     .10     .15     .15     .20     .20     .10     .15     .35     .25     .15     .25     .15     .20     .20     .25     .25     .15     .25
.15     .25     .30     .25     .25     .20     .20     .25     .35     .25     .15     .25     .15     .20     .25     .20     .15     .25     .45     .15
.10     .65     .25     .20     .25     .20     .25     .25     .15     .55     .15
        SAMPLING POSITION NO. 13.       REP. NO. 1.
.15     .10     .25     .20     .30     .20     .25     .45     .60     .25     .25     .10     .25     .20     .25     .35     .30     .25     .25     .35
.25     .30     .25     .25     .35     .25     .25     .25     .15     .25     .25     .20     .15     .25     .25     .20     .10     .20     .30     .20
.20     .30     .30     .40     .25     .30     .35     .25     .20     .35     .35     .25     .25     .25     .25     .25     .25     .25     .25     .25
.20     .25     .20     .20     .35     .25     .35     .25     .30     .15     .25     .30     .20     .20     .30     .15     .25     .40     .15     .75
.25     .25     .55     .25
        SAMPLING POSITION NO. 14.       REP. NO. 1.
.25     .35     .10     .25     .25     .25     .25     .15     .25     .35     .10     .10     .25     .10     .10     .25     .45     .20     .25     .25
.35     .35     .35     .45     .20     .25     .10     .20     .10     .25     .25     .10     .15     .20     .30     .10     .30     .35     .25     .45
.30     .30
        SAMPLING POSITION NO. 15.       REP. NO. 1.
.30     .40     .10     .10     .10     .10     .25     .30     .30     .30     .30     .10     .30     .50     .25     .10     .35     .30     .15     .10
        SAMPLING POSITION NO. 16.       REP. NO. 1.
.30     .30     .25     .15     .25     .35     .35     .25     .45     .25     .25     .10     .30     .25     .20     .25     .25     .20     .15     .25
.20     .45     .25     .10     .25     .30     .45     .35     .35     .20     .25     .25     .25     .30     .30     .25     .25     .25     .20     .20
.30     .30     .25     .20     .25     .30     .35     .25     .20     .25     .30     .15     .35     .15     .30     .20     .25     .25     .10     .25
.30     .35     .25     .25     .35     .25     .30     .25     .10     .15     .20
        SAMPLING POSITION NO. 17.       REP. NO. 1.
.30     .10     .10     .30     .25     .15     .10     .25     .20     .10     .20     .40     .35     .20     .15     .15     .10     .10     .10     .35
.40     .25     .15     .10     .10     .25     .35     .10     .30     .20     .10     .10     .10     .10     .10     .10     .10     .10     .10     .15
.35     .25     .35     .25     .10     .05     .05     .05     .05     .05     .05     .10     .10     .40     .25     .20     .35     .30     .10     .10
.10     .10     .25     .30     .70     .40     .60     .20     .10     .30     .35     .35     .10     .25     .25     .05     .05     .10     .35     .40
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APPENDIX E-I CONTINUED

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.10   .55   .10   .10   .05   .10   .10   .30
      SAMPLING POSITION NO. 18.     REP. NO. 1.
.20   .25   .25   .25   .25   .25   .10   .10   .20   .10   .10   .25   .25   .30   .25   .50   .20   .30   .40   .20
.25   .25   .25   .25   .35   .30   .25   .35   .50   .40   .25   .30   .25   .20   .25   .20   .05   .10   .20   .25
.25   .25   .20
      SAMPLING POSITION NO. 19.     REP. NO. 1.
.35   .25   .35   .20   .10   .50   .10   .30   .30   .10   .25   .25   .25   .25   .30   .35   .20   .40   .60   .25
.25   .25   .35   .30   .30   .30
      SAMPLING POSITION NO. 20.     REP. NO. 1.
.10   .25   .35   .10   .25   .30   .65   .30
      SAMPLING POSITION NO. 21.     REP. NO. 1.
.25   .20   .30   .20   .25   .30   .30   .10   .10   .25   .25   .30   .50   .10   .25   .25   .25   .10   .30   .25
.20   .20   .35   .30   .30   .10   .25   .35   .35   .25   .10   .35   .50   .25   .25   .35   .40   .35   .25   .25
.25   .25   .25   .50   .50   .25   .25   .10   .10   .10   .15   .25   .65   .30   .30
      SAMPLING POSITION NO. 22.     REP. NO. 1.
.30   .25   .25   .25   .25   .30   .25   .30   .25   .35   .50   .25   .25   .40   .30   .25   .30   .40   .40   .40
.45   .25   .30   .35   .20   .50   .25   .30   .10   .25   .30   .15   .45   .50   .30   .35   .25   .25   .25   .40
.30   .25   .50   .35   .25   .30
      SAMPLING POSITION NO. 23.     REP. NO. 1.
.20   .10   .05   .30   .15   .35   .35   .25   .25   .30   .35   .65   .20   .30   .25   .30   .05   .30   .20   .20
.35   .35   .25   .10   .40   .35   .20   .30   .40   .30   .10   .05   .50   .35   .45
      SAMPLING POSITION NO. 24.     REP. NO. 1.
.35   .30   .25   .25   .35   .20   .10   .10   .35   .35   .30   .15   .35   .20   .35   .30   .35   .35   .30   .25
.10   .10
      SAMPLING POSITION NO. 25.     REP. NO. 1.
.35   .40   .30   .30   .45   .25   .25   .30   .10   .25   .30   .30   .25   .30   .25   .15   .40   .45   .20   .30
.35   .30   .50   .25   .35   .35   .25   .25   .25   .25   .30   .25   .20   .25   .40   .40   .30   .25   .50   .25
.30   .15   .25   .40   .40   .30   .20   .30   .30
      SAMPLING POSITION NO. 26.     REP. NO. 1.
.30   .25   .30   .25   .30   .40   .30   .30   .30   .20   .35   .30   .25   .25   .30   .45   .30   .25   .25   .10
.40   .30   .30   .55   .45   .30   .25   .30   .30   .25   .30   .40
      SAMPLING POSITION NO. 27.     REP. NO. 1.
.30   .30   .30   .30   .20   .30   .25   .25   .10   .10   .50   .35   .35   .35   .30   .25   .30   .25   .35   .25
.30   .25   .30   .40   .50   .30   .35
      SAMPLING POSITION NO. 28.     REP. NO. 1.
.30   .30   .20   .25   .20   .30   .25   .30   .35
      SAMPLING POSITION NO. 29.     REP. NO. 1.
.25   .25   .30   .25   .30   .20   .30   .30   .25   .30   .40   .35   .30   .25   .45   .25
      SAMPLING POSITION NO. 30.     REP. NO. 1.
.25   .45   .30   .30   .30   .30   .50   .30   .40   .35   .25   .35   .35   .25   .30   .20
      SAMPLING POSITION NO. 31.     REP. NO. 1.
.10   .45   .35   .10   .30   .25   .40   .15   .30   .25   .45   .10   .35   .55   .30   .30   .30   .10   .10   .35
      SAMPLING POSITION NO. 32.     REP. NO. 1.
.15   .30   .30   .10   .60   .15
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APPENDIX E-I CONTINUED

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                                        SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                              DELAVAN FS-2-65 FAN NOZZLE
                                              DIESEL FUEL AT 20 PSI
                                              SAMPLING DISTANCE = 4 INCHES
                                              GRID CHART = 20 MM PER GRID UNIT
                                              CAMERA MAG = 8
                                              COMPARATOR MAG = 10
        SAMPLING POSITION NO.  1.       REP. NO. 2.
   .20   .25   .25   .25   .15   .25   .10   .20   .05   .10   .25   .20   .20   .15   .70   .20   .15   .15   .10   .25
   .15   .15   .20   .20   .25   .20   .15   .15   .10   .10   .15   .30   .10   .15   .15   .15   .15   .15   .10   .10
   .25   .15   .15   .15   .15   .30   .20   .15   .25   .15   .15   .15   .10   .20   .10   .20   .10   .10   .20   .20
   .15   .20   .20   .15   .20   .50   .10   .20   .25   .10   .25   .15   .15   .15   .20   .15   .15   .15   .15   .15
   .15   .50   .15   .15   .10   .20   .95   .10   .15   .15   .20   .10
        SAMPLING POSITION NO.  2.       REP. NO. 2.
   .30   .20   .40   .35   .25   .10   .10   .10   .20   .20   .30   .15   .10   .15   .10   .10   .50   .15   .15   .20
   .15   .20   .30   .15   .10   .15   .10   .15   .25   .20   .30   .30   .10   .10   .20   .30   .15   .20   .10   .10
   .25   .20   .15   .10   .10   .30   .15   .10   .10   .15
        SAMPLING POSITION NO.  3.       REP. NO. 2.
   .30   .40   .25   .25   .20   .10   .40   .10   .25   .20   .10   .10   .20   .10   .10   .15   .10   .10   .20   .25
   .25   .15   .25   .10   .25   .15   .15   .20   .20   .10   .05   .10   .25   .20   .10   .10   .05   .10   .20   .25
   .35   .10   .15   .30   .15   .10   .10   .20   .35   .10   .30   .15   .15   .55   .20   .20   .25   .15   .20
        SAMPLING POSITION NO.  4.       REP. NO. 2.
   .10   .05   .25   .25   .10   .10   .75  1.60  1.75   .35   .30   .25   .35   .10   .20   .10   .10   .35  1.60  1.70
   .40
        SAMPLING POSITION NO.  5.       REP. NO. 2.
   .25   .10   .10   .10   .10   .10   .40   .20   .05   .25   .25   .25
        SAMPLING POSITION NO.  6.       REP. NO. 2.
   .20   .20   .15   .15   .60   .15   .20   .10   .10   .40   .10   .15   .15   .10   .10   .10   .10   .10   .10   .15
   .45   .15   .50   .10   .10   .65   .10   .10   .35   .30   .15   .15   .30   .15   .15   .45   .15   .10   .15   .15
   .10   .10   .10   .20   .15   .15   .15   .15   .10   .10
        SAMPLING POSITION NO.  7.       REP. NO. 2.
   .10   .40   .15   .15   .15   .15   .20   .10   .15   .10   .20   .45   .15   .35   .15   .10   .10   .10   .15   .15
   .10   .10   .10   .15   .20   .15   .10   .30   .20   .15   .15   .15   .20   .20   .10   .10   .35   .10   .10   .15
   .15   .10   .15   .15   .15   .10   .10   .20   .10   .20   .25   .15   .10   .15   .15   .10   .55   .10   .10   .10
   .15   .10   .10   .15   .15   .15   .10   .10   .10   .15   .10   .25   .10   .10   .10
        SAMPLING POSITION NO.  8.       REP. NO. 2.
   .25   .10   .15   .10   .10   .15   .05   .25   .10   .15   .15   .20   .20   .20   .30   .25   .10   .20   .05   .05
   .25   .20   .10   .10   .15   .25   .15   .05   .25   .10   .35   .20   .20
        SAMPLING POSITION NO.  9.       REP. NO. 2.
   .30   .25   .25   .05   .05   .10   .35   .25   .15   .30   .30
        SAMPLING POSITION NO. 10.       REP. NO. 2.
   .10   .45   .20   .25   .25   .25   .30   .25   .05   .30   .25   .05   .30   .25   .10   .30   .30
        SAMPLING POSITION NO. 11.       REP. NO. 2.
   .35   .15   .10   .35   .25   .20   .10   .15   .10   .25   .20   .10   .15   .15   .15   .25   .15   .15   .25   .10
   .25   .20   .30   .20   .80   .10   .20   .15   .30   .10   .20   .25   .15   .20   .15   .15   .15   .15   .15   .10
   .15   .15   .15   .10   .10   .15   .25   .15   .20   .10   .25   .20   .15   .25   .20   .15   .15   .15   .15   .10
   .20   .15   .15   .10   .10   .20   .30   .10   .15   .25
        SAMPLING POSITION NO. 12.       REP. NO. 2.
   .15   .20   .10   .25   .20   .20   .10   .30   .10   .15   .25   .10   .10   .40   .10   .10   .35   .10   .50   .10
   .15   .20   .25   .20   .20   .25   .15   .20   .25   .20   .30   .20   .20   .10   .20   .25   .20   .20   .15   .15
   .20   .25   .10   .10   .10   .20   .10   .05   .10   .25   .15   .25   .15   .30   .20   .10   .25   .25   .15   .25
   .15   .10   .20   .25   .25   .20   .25   .25
        SAMPLING POSITION NO. 13.       REP. NO. 2.
   .20   .25   .25   .25   .30   .15   .30   .75   .25   .25   .10   .25   .30   .10   .35   .30   .15   .30   .30   .35
   .20
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APPENDIX E-I CONTINUED

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     SAMPLING POSITION NO. 14.       REP. NO. 2.
.15   .10   .40   .20   .20   .10   .10   .10   .20   .30   .15   .10   .10   .10   .30   .30   .25   .10   .20   .20
.20   .45
     SAMPLING POSITION NO. 15.       REP. NO. 2.
.25   .40   .10   .25   .25   .30   .10
     SAMPLING POSITION NO. 16.       REP. NO. 2.
.20   .20   .25   .15   .10   .10   .10   .25   .10   .10   .10   .35   .35   .10   .20   .20   .15   .30   .05   .20
.15   .05   .40   .30   .15   .10   .20   .20   .20   .10   .10   .10   .15   .30   .10   .30   .20   .20   .15   .20
.25   .10   .25   .20   .15   .40   .10   .15
     SAMPLING POSITION NO. 17.       REP. NO. 2.
.25   .25   .20   .55   .25   .10   .25   .20   .15   .10   .25   .20   .10   .05   .25   .35   .25   .20   .15   .10
.10   .10   .20   .15   .20   .10   .25   .10   .10   .15   .30   .25   .35   .10   .25   .10   .10   .15   .15   .75
.35   .15   .20   .20   .10
     SAMPLING POSITION NO. 18.       REP. NO. 2.
.25   .40   .25   .15   .15   .35   .15   .20   .25   .25   .25   .35   .25   .20   .25   .25   .25   .80   .25   .20
.30   .20   .20
     SAMPLING POSITION NO. 19.       REP. NO. 2.
.45   .30   .25   .25   .70   .35   .30   .25   .10
     SAMPLING POSITION NO. 20.       REP. NO. 2.
.20   .35   .10   .35   .10   .10   .20   .05   .05   .10   .15   .20
     SAMPLING POSITION NO. 21.       REP. NO. 2.
.25   .25   .30   .20   .20   .25   .30   .30   .20   .55   .45   .25   .20   .25   .20   .35   .10   .20   .30   .50
.25   .15   .25   .30   .30   .25
     SAMPLING POSITION NO. 22.       REP. NO. 2.
.25   .30   .15   .10   .20   .10   .30   .15   .15   .20   .25   .35   .05   .15   .15   .20   .25   .20   .15   .35
.25   .05   .40   .20   .30   .25   .40   .20
     SAMPLING POSITION NO. 23.       REP. NO. 2.
.25   .50   .25   .20   .20   .20   .20   .25   .25   .20   .10   .15   .20   .25   .25   .20   .25   .35   .50   .20
.30   .15
     SAMPLING POSITION NO. 24.       REP. NO. 2.
.35   .50   .25   .35   .50   .10   .40   .05   .25
     SAMPLING POSITION NO. 25.       REP. NO. 2.
.15   .65   .50   .30   .25   .50   .30   .35   .25   .30   .25
     SAMPLING POSITION NO. 26.       REP. NO. 2.
.15   .20   .25   .25   .40   .05   .35   .30
     SAMPLING POSITION NO. 27.       REP. NO. 2.
.30   .35   .25   .30   .10   .35   .25   .25   .35   .25   .30   .10
     SAMPLING POSITION NO. 28.       REP. NO. 2.
.25   .40   .30   .10   .25   .30   .25   .15
     SAMPLING POSITION NO. 29.       REP. NO. 2.
.45   .35   .10   .45   .10   .10   .50   .30
     SAMPLING POSITION NO. 30.       REP. NO. 2.
.35   .25   .30   .30   .35   .30
     SAMPLING POSITION NO. 31.       REP. NO. 2.
.30   .30   .30   .30   .25   .10   .10   .10   .35   .10   .40
     SAMPLING POSITION NO. 32.       REP. NO. 2.
.15   .10   .05   .15   .10   .10   .30   .25   .35   .30
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APPENDIX E-I CONTINUED

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                                          SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                                 DELAVAN FS-2-65 FAN NOZZLE
                                                 DIESEL FUEL AT 20 PSI
                                                 SAMPLING DISTANCE = 4 INCHES
                                                 GRID CHART = 20 MM PER GRID UNIT
                                                 CAMERA MAG = 8
                                                 COMPARATOR MAG = 10
       SAMPLING POSITION NO.  1.          REP. NO. 3.
.15    .15    .35    .15    .10    .15    .15    .20    .10    .20    .25    .10    .25    .15    .75    .15    .20    .20    .25    .20
.10    .15    .15    .15    .10    .25    .15    .45    .15    .05    .25    .30    .15    .10    .20    .10    .20    .20    .25    .20
.10    .20    .15    .10    .20    .05    .15    .15    .10    .20    .30    .10    .25    .25    .15    .20    .15    .15    .10    .30
.10    .10    .55    .05    .10    .20    .10    .15    .10    .45    .30    .10    .10    .15    .25    .20    .15    .25    .15    .20
.15    .20    .10    .20    .10    .30    .10    .10    .15    .25    .10    .15    .25    .15    .10    .05    .70    .10    .25    .80
.10    .15    .20    .10    .15    .20    .10    .10    .05    .10
       SAMPLING POSITION NO.  2.          REP. NO. 3.
.20    .15    .25    .25    .30    .25    .20    .20    .25    .20    .10    .20    .10    .10    .35    .30    .30    .10    .25    .70
.20    .65    .15    .25    .15    .15    .20    .05    .70    .25    .70    .05    .20    .20
       SAMPLING POSITION NO.  3.          REP. NO. 3.
.25    .10    .15    .15    .10    .05    .25    .30    .15    .15    .20    .10    .50    .15    .20    .15    .20    .75    .10    .10
.15    .15    .15    .35    .20    .15    .10    .70    .15    .25    .20    .20    .20    .10    .30    .20    .15    .15    .10    .15
.20    .10    .15    .75    .15    .35    .15    .20    .30    .15    .30    .20    .15    .15    .15    .20    .30    .15    .10    .20
.15    .50    .10    .25    .15    .15    .05    .25    .20    .20    .25    .25    .20    .25    .10    .20    .25    .30    .45    .45
.15    .15    .10    .25    .35    .20    .20    .15    .45    .15    .20    .25    .25    .15    .25    .20    .35    .40    .15    .25
.20    .25    .75
       SAMPLING POSITION NO.  4.          REP. NO. 3.
.15    .15    .25    .10    .10    .25    .05    .25    .20    .10    .20    .35    .15    .25    .25    .15    .10    .20    .10    .25
.15    .20    .45    .15    .25   1.65   1.60   1.95   1.25   2.00   1.60   1.90   1.05
       SAMPLING POSITION NO.  5.          REP. NO. 3.
.20    .30    .30    .30    .25    .10    .05    .10    .30    .30    .25    .10    .10    .50    .25    .30    .30    .10    .10    .05
.10
       SAMPLING POSITION NO.  6.          REP. NO. 3.
.15    .20    .15    .10    .20    .15    .15    .15    .05    .15    .25    .25    .10    .10    .15    .10    .35    .10    .05    .35
.25    .20    .25    .10    .25    .85    .30    .15    .30    .25    .15    .10    .15    .15    .35    .60    .20    .40    .15    .45
.30    .10    .15    .15    .20    .15    .15    .30    .20    .10    .30    .15    .40    .20    .10    .20    .30    .20    .30    .25
.50    .20    .30    .30    .15    .25    .10    .20    .20    .25    .25    .15    .15    .20    .05    .10    .15    .25    .10    .15
.20    .10    .10    .20    .25    .35    .25    .50    .30    .30    .30    .35    .25    .40    .25
       SAMPLING POSITION NO.  7.          REP. NO. 3.
.20    .10    .20    .15    .35    .40    .15    .20    .10    .30    .25    .25    .15    .30    .30    .20    .25    .10    .10    .30
.75    .45    .35    .10    .15    .50    .25    .50    .25    .25    .20    .20    .20    .20    .10    .15    .15    .20
       SAMPLING POSITION NO.  8.          REP. NO. 3.
.25    .25    .40    .25    .25    .40    .30    .25    .20    .25    .30    .40    .40    .25    .20    .25    .30    .25    .60    .25
.25    .10    .90    .25    .25    .15    .30    .55    .05    .30    .30    .25    .20    .05    .10    .20    .25    .25    .25    .35
.15    .25    .05    .25    .30    .25    .20    .25    .25    .40    .25    .25    .35
       SAMPLING POSITION NO.  9.          REP. NO. 3.
.20    .25    .20    .40    .25    .10    .10    .20    .15    .30    .20    .15    .35    .15    .20    .20    .40    .15    .15    .85
.10    .20    .25
       SAMPLING POSITION NO. 10.          REP. NO. 3.
.30    .25    .25    .25    .45    .30    .35    .25    .25    .25    .25    .30    .25    .35    .25    .25    .25    .30
       SAMPLING POSITION NO. 11.          REP. NO. 3.
.20    .20    .20    .15    .25    .25    .25    .10    .05    .15    .20    .05    .15    .15    .30    .15    .35    .20    .10    .15
.15    .15    .10    .25    .30    .45    .30    .25    .10    .10    .15    .20    .25    .10    .20    .25    .15    .25    .10    .20
.10    .75    .10    .50    .25    .10    .25    .20    .10    .35    .55    .35    .25    .15    .15    .15    .50    .15    .10    .15
.10    .15    .25    .30    .15    .15    .10    .25    .25    .20    .20    .25    .25    .55    .15    .10    .25    .10    .25    .20
.50    .25    .15    .10    .25    .25    .50
       SAMPLING POSITION NO. 12.          REP. NO. 3.
.30    .20    .20    .25    .35    .25    .45    .20    .20    .35    .15    .15    .20    .20    .25    .20    .15    .20    .15    .30
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APPENDIX E-I   CONTINUED

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.50   .30   .20   .30   .40   .15   .10   .35   .30   .20   .20   .15   .15   .40   .20   .20   .25   .05
      SAMPLING POSITION NO. 13.     REP. NO. 3.
.20   .20   .15   .75   .25   .40   .35   .25   .25   .30   .35   .30   .35   .25   .25   .30   .30   .10   .25   .30
.35   .25   .10   .20   .25   .15   .20   .25   .15   .10   .10   .10   .55   .25   .30   .25   .20   .20   .25   .30
      SAMPLING POSITION NO. 14.     REP. NO. 3.
.25   .40   .30   .40   .25   .30   .20   .45   .40   .25   .35   .25   .45   .35   .25   .25   .25   .20   .30
      SAMPLING POSITION NO. 15.     REP. NO. 3.
.30   .25   .25   .10   .30   .10   .20   .25   .25   .30
      SAMPLING POSITION NO. 16.     REP. NO. 3.
.25   .25   .15   .25   .10   .20   .25   .20   .05   .15   .10   .35   .20   .15   .10   .30   .25   .25   .25   .30
.20   .20   .40   .25   .30   .30   .20   .30   .35   .20   .20   .20   .20   .20   .15   .25   .25   .25   .25   .30
.15   .25  1.15   .35   .15   .20   .25   .20   .20   .20   .25   .60   .15   .10   .15   .15   .10   .35   .30   .20
.20   .25   .15   .40   .30   .20   .20   .15   .30   .25   .30   .15   .20   .30   .25   .20   .25   .20   .20   .35
.20   .30   .25   .25   .55
      SAMPLING POSITION NO. 17.     REP. NO. 3.
.25   .25   .15   .10   .25   .25   .25   .15   .25   .20   .10   .25   .10   .05   .10   .10   .20   .25   .15   .10
.25   .30   .30   .15   .30   .25   .15   .20   .30   .30   .10   .35   .25   .35   .25   .20   .25   .25   .30   .30
.25
      SAMPLING POSITION NO. 18.     REP. NO. 3.
.25   .25   .20   .25   .50   .30   .15   .20   .25   .30   .30   .90   .25   .25   .30   .25   .25   .25   .30   .20
.15   .20   .15   .20   .25   .30   .25   .30   .25   .25   .30
      SAMPLING POSITION NO. 19.     REP. NO. 3.
.25   .30   .25   .30   .25   .30   .25   .25   .25   .25   .20   .30
      SAMPLING POSITION NO. 20.     REP. NO. 3.
.25   .25   .30   .30   .35   .25
      SAMPLING POSITION NO. 21.     REP. NO. 3.
.25   .30   .25   .35   .30   .15   .25   .20   .10   .30   .35   .25   .25   .40   .30   .30   .25   .30   .10   .10
.45   .30   .30   .25   .25   .25   .10   .25   .30   .25   .30   .35   .25   .25   .20   .30   .25   .25   .40   .30
.25   .05
      SAMPLING POSITION NO. 22.     REP. NO. 3.
.30   .25   .45   .25   .30   .40   .25   .20   .30   .30   .35   .25   .30   .50   .35   .25   .65   .55   .10   .30
.25
      SAMPLING POSITION NO. 23.     REP. NO. 3.
.25   .30   .35   .25   .40   .25   .40   .25   .25   .30   .35   .45   .15   .30   .30   .30   .30   .25
      SAMPLING POSITION NO. 24.     REP. NO. 3.
.55   .25   .15   .45   .10   .25   .25
      SAMPLING POSITION NO. 25.     REP. NO. 3.
.40   .55   .35   .25   .45   .35   .10   .35   .25   .35   .35   .35   .30   .35   .30   .30   .30   .40   .30   .45
.30   .10
      SAMPLING POSITION NO. 26.     REP. NO. 3.
.10   .35   .25   .30   .10   .30   .35   .25   .10   .35   .30   .55   .30   .10   .30
      SAMPLING POSITION NO. 27.     REP. NO. 3.
.25   .05   .05   .25   .50   .30   .35   .30   .30   .40   .40   .10   .10   .10   .10
      SAMPLING POSITION NO. 28.     REP. NO. 3.
.10   .25   .35
      SAMPLING POSITION NO. 29.     REP. NO. 3.
.25   .30   .30   .40   .40   .20   .30   .30   .35   .30   .15   .35
      SAMPLING POSITION NO. 30.     REP. NO. 3.
.25   .45   .15   .25   .10   .05   .30   .40   .30   .25   .35   .35   .50   .30
      SAMPLING POSITION NO. 31.     REP. NO. 3.
.45   .10   .50   .25   .25   .35   .05   .50   .25   .30
      SAMPLING POSITION NO. 32.     REP. NO. 3.
.35   .35   .10
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APPENDIX E-I CONTINUED

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                                    SAMPLING PATTERN DATA (GRID READING DIAMETERS)
                                          DELAVAN FS-2-65 FAN NOZZLE
                                          DIESEL FUEL AT 20 PSI
                                          SAMPLING DISTANCE = 4 INCHES
                                          GRID CHART = 20 MM PER GRID UNIT
                                          CAMERA MAG = 8
                                          COMPARATOR MAG = 10
      SAMPLING POSITION NO.  1.     REP. NO. 4.
 .15   .55   .55   .15   .20   .15   .45   .10   .20   .15   .25   .25   .20   .20   .20   .35   .15   .20   .15   .15
 .20   .25   .30   .15   .75   .15   .20   .15   .15   .25   .15   .15   .10   .20   .10   .30   .20   .35   .10   .20
 .25   .15   .20   .20   .10   .10   .10   .35   .20
      SAMPLING POSITION NO.  2.     REP. NO. 4.
 .65   .20   .20   .35   .10   .25   .40   .10   .25   .15   .10   .10   .20   .25   .15   .20   .10   .30   .35   .20
 .15   .20   .20   .25   .30   .15   .15   .25   .25   .20   .25   .45   .20
      SAMPLING POSITION NO.  3.     REP. NO. 4.
 .40   .45   .25   .40   .30   .25   .10   .25   .10   .25   .20   .20   .25   .25   .15   .20   .20   .25   .20   .20
 .15   .20   .10   .20   .30   .30   .25   .25   .20   .15   .10   .20   .25   .45   .25   .15   .25   .55   .10   .30
 .45   .50   .15   .30   .15   .35   .20   .25   .30   .20   .15   .20
      SAMPLING POSITION NO.  4.     REP. NO. 4.
 .25   .25   .60  1.15   .30   .10   .15   .30   .25   .20   .45  1.05  1.25  1.45  1.35  1.80  1.25  1.40  1.50
      SAMPLING POSITION NO.  5.     REP. NO. 4.
 .30   .25   .25   .45   .25   .30
      SAMPLING POSITION NO.  6.     REP. NO. 4.
 .55   .10   .10   .20   .45   .20   .20   .20   .35   .25   .10   .15   .15   .25   .15   .15   .20   .30   .40   .25
1.20   .40   .25   .65   .15   .30   .75   .50   .20   .15   .40
      SAMPLING POSITION NO.  7.     REP. NO. 4.
 .20   .10   .15   .15   .30   .20   .35   .25   .15   .10   .20   .45   .30   .80   .30   .15   .30   .40   .15   .10
 .15   .20   .20   .30   .40   .25   .15   .25   .25   .15   .15   .15   .15   .20   .15   .15   .40   .25   .15   .20
      SAMPLING POSITION NO.  8.     REP. NO. 4.
 .25   .25   .20   .20   .20   .35   .30   .20   .20   .25   .10   .20   .10   .30   .20   .20   .30   .25
      SAMPLING POSITION NO.  9.     REP. NO. 4.
 .10   .25   .35   .30   .05   .10   .05   .25   .25   .30   .05   .05
      SAMPLING POSITION NO. 10.     REP. NO. 4.
 .20   .25   .25   .20   .25   .25   .30   .25
      SAMPLING POSITION NO. 11.     REP. NO. 4.
 .35   .25   .55   .15   .25   .25   .30   .55   .10   .25   .15   .15   .15   .15   .30   .10   .20   .10   .25   .10
 .10   .10   .10   .10   .35   .20   .15   .20   .10   .20   .15   .25   .25   .50   .25   .25   .30   .25   .25   .25
 .25   .10   .15   .15   .25   .25   .30   .25   .20   .15   .25   .30   .40   .30   .20   .20   .15   .25   .45   .20
 .20
      SAMPLING POSITION NO. 12.     REP. NO. 4.
 .50   .30   .25   .25   .45   .15   .10   .35   .25   .15   .25   .10   .25   .25   .20   .15   .50   .10   .30   .25
 .30   .20   .15   .15   .10   .15   .25   .40   .25   .20
      SAMPLING POSITION NO. 13.     REP. NO. 4.
 .20   .20   .25   .25   .15   .10   .25   .25   .25   .20   .25   .25   .20   .30   .25   .25   .10   .10   .25   .10
 .10   .05   .25   .10   .25   .10   .10   .15   .10   .10   .10   .10   .15   .25   .20   .15   .25   .25   .15   .10
 .20
      SAMPLING POSITION NO. 14.     REP. NO. 4.
 .15   .25   .30   .20   .20   .25   .25   .15   .25   .15   .25
      SAMPLING POSITION NO. 15.     REP. NO. 4.
 .25   .25   .30   .10   .25   .25   .20
      SAMPLING POSITION NO. 16.     REP. NO. 4.
 .15   .20   .10   .20   .20   .25   .35   .10   .25   .45   .20   .20   .25   .25   .20   .30   .25   .25   .25   .15
 .30   .25   .25   .10   .20   .30   .25   .25   .25   .25   .25   .20   .25   .25   .30   .40
      SAMPLING POSITION NO. 17.     REP. NO. 4.
 .25   .20   .20   .40   .25   .25   .25   .35   .40   .10   .40   .25   .30   .25   .40   .25   .25   .30   .25   .30
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.35   .25   .25   .25   .20   .25   .30
     SAMPLING POSITION NO. 18.        REP. NO. 4.
.25   .20   .25   .30   .20   .25   .25   .25   .60   .10   .25   .20   .25   .25   .30   .25
     SAMPLING POSITION NO. 19.        REP. NO. 4.
.30   .30   .25   .25   .25   .25   .30   .25   .50   .20   .25   .10   .25
     SAMPLING POSITION NO. 20.        REP. NO. 4.
.30   .25   .25   .30   .35
     SAMPLING POSITION NO. 21.        REP. NO. 4.
.35   .25   .25   .10   .25   .30   .30   .25   .05   .05   .25   .35   .25   .25
     SAMPLING POSITION NO. 22.        REP. NO. 4.
.25   .30   .40   .25   .25   .45   .30   .25   .25   .25   .25   .40   .20   .25   .30   .25
     SAMPLING POSITION NO. 23.        REP. NO. 4.
.25   .25   .25   .30   .20   .25   .25   .25   .30   .25   .25   .25   .40   .30
     SAMPLING POSITION NO. 24.        REP. NO. 4.
.35   .35   .10   .35   .10   .15   .10   .10   .10
     SAMPLING POSITION NO. 25.        REP. NO. 4.
.55   .30   .35   .25   .25   .45   .25
     SAMPLING POSITION NO. 26.        REP. NO. 4.
.25   .35   .25   .30   .10   .10   .55   .10   .15   .10
     SAMPLING POSITION NO. 27.        REP. NO. 4.
.50   .25   .25   .30   .10
     SAMPLING POSITION NO. 28.        REP. NO. 4.
.25   .05   .10
     SAMPLING POSITION NO. 29.        REP. NO. 4.
.10   .10   .05   .05   .05
     SAMPLING POSITION NO. 30.        REP. NO. 4.
.15   .35   .10   .10   .05   .35   .05   .05
     SAMPLING POSITION NO. 31.        REP. NO. 4.
.25   .25   .10   .40   .30   .10
     SAMPLING POSITION NO. 32.        REP. NO. 4.
.30   .30   .30
```

APPENDIX E-II

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
WATER AT 40 PSI
SAMPLING DISTANCE = 6. INCHES

REPLICATION 1.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	2	7	11	2	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	1	6	10	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	7	5	8	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	2	8	12	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	12	13	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	5	4	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	3	1	5	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
8	1	17	13	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	20	10	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
10	0	9	7	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
11	2	11	11	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	12	11	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	2	4	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	2	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	1	5	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	3	2	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	1	2	5	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
19	1	1	3	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
20	0	2	2	1	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	5	5	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	2	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	1	3	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	3	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
29	3	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
WATER AT 40 PSI
SAMPLING DISTANCE = 6. INCHES

REPLICATION 2.

	DROP SIZE CLASS (MICRONS)																			
SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	1	8	17	8	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	5	17	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	13	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5	4	7	0	2	0	2	1	0	1	0	0	0	0	0	0	0	0	0	0
5	1	2	3	3	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6	2	1	6	1	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
7	1	1	6	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	12	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	4	8	3	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	1	7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	8	7	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
12	1	0	2	4	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
13	1	0	1	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	1	6	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2	8	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	3	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	2	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
26	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
WATER AT 40 PSI
SAMPLING DISTANCE = 6. INCHES

REPLICATION 3.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	2	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5	5	2	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4	6	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	2	11	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	4	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	2	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
9	6	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	3	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	2	2	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	2	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	5	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	8	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	1	0	3	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
25	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
WATER AT 40 PSI
SAMPLING DISTANCE = 6. INCHES

REPLICATION 4.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	5	9	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	1	4	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4	0	3	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	3	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	1	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	6	8	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	2	7	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	3	6	2	2	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
12	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	2	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
15	0	2	3	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	3	5	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	2	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	2	3	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	2	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
32	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
DIESEL OIL AT 20 PSI
SAMPLING DISTANCE = 4. INCHES

REPLICATION 1.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	41	46	37	13	7	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
2	46	65	34	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	32	31	23	6	6	3	0	2	2	0	0	0	0	0	0	0	0	0	0	0
4	20	17	21	6	5	3	3	0	0	0	1	0	0	1	1	0	2	2	0	1
5	7	1	15	9	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	39	60	31	6	7	5	3	1	0	0	1	0	0	0	0	0	0	0	0	0
7	23	44	27	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	12	37	36	7	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	9	7	28	17	11	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	4	3	11	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	62	49	29	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	26	62	31	4	5	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
13	3	20	47	10	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	9	6	18	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	7	1	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	4	15	41	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	43	11	17	14	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	6	8	23	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	3	2	14	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	2	0	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	9	5	29	7	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	2	28	9	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	6	6	11	9	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
24	4	3	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1	5	29	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1	1	23	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	2	1	16	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	2	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	1	12	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	1	9	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	5	1	7	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	1	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
DIESEL OIL AT 20 PSI
SAMPLING DISTANCE = 4. INCHES

REPLICATION 2.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	18	57	13	0	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
2	16	21	10	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	20	21	13	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	7	1	4	4	0	0	0	1	0	0	0	0	0	0	0	2	1	1	0	0
5	6	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	19	22	2	2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	32	35	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	12	13	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	1	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	4	1	11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	15	39	13	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
12	18	28	19	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	2	4	12	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	8	8	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	2	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	16	20	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	14	15	11	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
18	0	8	11	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	5	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	6	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1	7	14	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	4	12	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1	10	8	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	2	0	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	1	6	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	2	0	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	3	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	4	0	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	4	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
DIESEL OIL AT 20 PSI
SAMPLING DISTANCE = 4. INCHES

REPLICATION 3.

DROP SIZE CLASS (MICRONS)

SAMPLING	1	26	51	75	101	126	151	176	201	226	251	276	301	326	351	376	401	426	451	476
POSITION	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500
1	36	49	18	1	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
2	6	13	10	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
3	15	53	21	5	5	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0
4	6	10	7	1	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	2
5	9	1	10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	18	37	27	8	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
7	6	15	10	3	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	5	7	31	7	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9	3	12	4	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
10	0	0	15	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	19	32	25	3	5	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
12	2	20	9	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	5	9	19	5	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	0	2	10	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	2	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	6	36	33	7	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0
17	8	9	22	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	8	21	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
19	0	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	5	3	28	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1	1	12	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	1	12	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1	1	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	2	0	8	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	4	0	7	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	6	0	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	2	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	2	1	6	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	2	0	4	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX E-II CONTINUED

SAMPLING PATTERN DATA (NUMBER OF DROPS IN EACH SIZE CLASS)

DELAVAN FS-2-65 FAN NOZZLE
DIESEL OIL AT 20 PSI
SAMPLING DISTANCE = 4. INCHES

REPLICATION 4.

DROP SIZE CLASS (MICRONS)

SAMPLING POSITION	1 25	26 50	51 75	75 100	101 125	126 150	151 175	176 200	201 225	226 250	251 275	276 300	301 325	326 350	351 375	376 400	401 425	426 450	451 475	476 500
1	7	28	7	3	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	5	14	9	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5	20	19	3	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	2	5	0	1	1	0	0	0	0	1	1	2	2	2	0	0	1	0	0
5	0	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	3	12	6	4	2	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0
7	3	21	10	4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	2	8	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	6	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	20	24	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	4	9	12	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	14	11	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	3	10	20	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	3	17	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	3	11	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	1	10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	3	0	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	1	12	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	1	12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	5	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	4	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	4	1	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	5	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	2	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VITA

Lawrence Orval Roth

Candidate for the Degree of

Doctor of Philosophy

Thesis: LIQUID ATOMIZATION RELATED TO THE PRODUCTION AND MEASUREMENT OF SPRAY PARTICLES

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Vernon County, Wisconsin, June 7, 1928, the son of Norman O. and Lulu Belle Roth.

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Professional Experience: Student Research Assistant, Agricultural Engineering Department, University of Wisconsin, 1949-1951. Instructor (Teaching and Research) Agricultural Engineering Department, Oklahoma State University, 1951-1956. Assistant Professor, Agricultural Engineering Department, Oklahoma State University, 1956-1965.

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