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CRANFIELD INSTITUTE OF TECHNOLOGY
NATIONAL COLLEGE OF AGRICULTURAL ENGINEERING

M.Sc. Thesis
for the Academic Year 1982-1983

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The Effect of Disc Deterioration on the Performance of
Ultra Low Volume Sprayer

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September 1983

Submitted in partial fulfilment of the requirements
for the M.Sc. Degree in Agricultural Engineering

SYNOPSIS

A laboratory study was formulated to investigate the effect of spinning disc deterioration (damage of disc teeth and surface groove clogging) on the performance of ultra low volume sprayer.

To do this, artificial teeth damages of varying degrees of severity were inflicted on three of five chosen identical spinning discs of 'Micron micro ulva' battery operated spinning disc ultra low volume sprayer. The fourth disc has its surface grooves artificially blocked and the fifth disc used as a control.

Droplet samples were obtained from each of the differently treated discs and the control disc at random and measured using a particle size analyser. The Volume median diameters (Vmds), Number median diameters (NmDs), Dispersion- ratios (r), for each set of droplet samples were obtained. Also power consumptions for each of the discs when spraying were measured.

There was found to be significant changes in droplet spectra with spinning disc deterioration, indicated by progressively higher values of volume median diameters, which is suggested to be attributed to the change of issuing points of droplets. There was, however, found to be no significant change in average droplet sizes (NmDs), but droplets were found to become less uniform with disc deterioration, indicated by higher values of dispersion ratios! (r). Power consumption was found to increase with disc damage, which would reflect on running costs of the machine, a factor which the user should be aware of.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Prof. F M Inns for his advice at various stages of the project. I would also like to thank the staff of the Overseas Spraying Machinery Centre (OSMC), Imperial College at Silwood Park, Ascot, Berks, UK for their suggestions and help in various forms. Thanks also go to Turbair Ltd for supplying the formulation used for this investigation free of charge. I would also like to thank Mr D H Noble, Mr D Morgan and Miss M Dales for their suggestions during the design and execution of the experiments.

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UNITS, ABBREVIATIONS AND SYMBOLSUnits

bar	barometric pressure	MN	mega Newton
cm ³	cubic centimetre	m/s	metre per second
g	gram	rad	radian
m	metre	v	volt
m ³	cubic metre	W	watt
mm	millimetre		
ml/s	millilitre per second		

Abbreviations and Symbols

C	control disc
CDA	controlled droplet application
Cf	compared with
CL	clogged groove disc
DC	direct current
DM	mean droplet size
DM**3	cube of mean diameter
E%N	cumulative percentage by number
E%NDM**3	cumulative percentage by volume
H	heavily damaged disc
ICI	Imperial Chemical Industry
L	light teeth damaged disc
LSD	least significant difference
M	medium teeth damaged disc or spinning disc electric motor
mph	mile per hour
N	number of droplets from each size class
Nmd	number median diameter
OSMC	Overseas Spraying Machinery Centre
PTO	power take off
rh	relative humidity
r	number of replicates
(r)	dispersion ratio
S	total sum of squares
St	sum of squares due to differences between treatments

Abbreviations and Symbols (contd.)

SUM N	total number of drops from all size classes
ULV	ultra low volume
V _{md}	volume median diameter
w	angular velocity
%N	percentage droplets for each class
γ	surface tension
ρ	density
<	is less than
>	is greater than

CHAPTER I

PROJECT BACKGROUND AND LITERATURE REVIEW

1.1 Introduction

A lot of work has been done on design and development of various ultra low volume (ULV) spinning disc spraying machines (Centrifugal sprayers or rotary atomisers, consisting essentially of a rotating disc from which edge droplets are formed when spray liquid is fed on it).

This led to the presence of various classes and types of these machines in the market today used for the control of different types of pests (eg insects/diseases or weeds) and hence producing different droplet spectra to suit the different purposes.

Like all other types of sprayers, ULV spinning disc sprayers are normally tested and evaluated when new by the manufacturer or some testing centre and the test results containing performance characteristics such as droplet spectrum, power consumption etc are produced.

The results of the evaluation tests, apart from giving clues to the manufacturer to improve upon design or guidance to buying agencies for making selection between several available makes, also helps the user (the farmer) to decide about the machine's suitability for his requirements.

Unfortunately, performance characteristics obtained from those test results (eg sizes and uniformity of droplets) may not necessarily remain unchanged with continuous usage of these machines with time, due to possible deteriorations of the machines or accidental damages of their delicate parts such as the spinning disc. The spinning disc of an ultra low volume sprayer for instance could get damaged when its edge is passed through tough crop stems or get blocked with some chemical when not properly maintained. Very little has been done so far to find out what sort of changes might occur with usage and what effects they may have on pest control.

This work attempts to investigate the sort of changes of performances of ultra low volume spinning disc sprayers that are likely to occur due to spinning disc deteriorations as a result of damage of parts or otherwise. This is in the hope that the user in particular (the farmer in this case) would be aware of the likely consequences, if any, of spinning disc deterioration with regard to his crop protection against pests.

1.2 Review of Literature

1.21 Classification of agricultural sprayers

Agricultural sprayers could be classified into five main groups according to the type of energy used in liquid atomisation within the sprayer, viz:

- (1) Hydraulic pressure energy sprayers
- (2) Gaseous energy sprayers
- (3) Thermal energy sprayers
- (4) Electrical energy sprayers
- (5) Centrifugal energy sprayers

All the five classes of sprayers mentioned above have similar basic components. Each consists of some form of pesticide storage volume or the tank, a pump or a gravity feed system of some sort and an atomisation or discharge unit. The principal difference between each of the above classes of sprayers is the method of pesticide atomisation.

1.211 Hydraulic pressure energy sprayer

Spray from hydraulic energy nozzled sprayers is formed by forcing liquid under pressure through an orifice. A sheet of liquid is formed which becomes attenuated and breaks up into droplets, typically ranging in sizes from one or two microns to several hundreds micrometers in diameter. Properties of liquid, such as surface tension, density, viscosity and ambient air conditions, all influence the development of the sheet (Matthews, 1979). Minimum pressure for most hydraulic nozzles is at least 1.0 bar, increase in pressure at the nozzle or

a decrease in surface tension, or viscosity of spray liquid or orifice size results in decrease in droplet size.

There are various types of hydraulic sprayers, but the principal ones include:

- a) Knapsack hydraulic sprayers: These include either lever operated types consisting of about 12-15 litre tanks, a hand operated pump, a pressure chamber and a lance with an on and off tap or trigger valve and one or more nozzles; or compressure types in which the tanks are pressurised before spraying. The latter allows the operator to give more attention to directing the nozzle at the correct target in contrast to continuous pumping needed with lever operated type.
- b) Power operated hydraulic sprayers: These range from small hand held engine driven pump units to large self-propelled sprayers. A typical type of such sprayers is a tractor mounted type with a series of nozzles mounted along a boom and a pump driven from a tractor power take-off (PTO). They are used for large scaled high volume spraying of field crops 50-500 litres per hectare.

Hydraulic sprayers have a number of merits associated with them and at present have been most widely used in comparison with others. Considerable flexibility can be achieved by interchanging the tips in their standard nozzle bodies, to provide a wide range of outputs and spray pattern at low costs. They however have a number of limitations as well. They deliver droplets of very wide range of sizes (eg 10-1000 microns) owing to irregular break up and are generally high volume types which would be a serious limitation in arid and semi-arid regions (such as some parts of Northern Nigeria) where water is a constraint.

1.212 Gaseous energy sprayers

These are otherwise known as air carrier, air blast or twin fluid sprayers. The central feature of these machines is the fan unit, which could be either centrifugal, propeller or axial. Typical of these machines is the motorised knapsack mistblower, consisting of basically

pesticide and fuel tanks with a fan unit powered by a two-stroke internal combustion engine. Extending from the fan casing is air discharge hose, which extend to the gaseous energy nozzle. Pesticide coming from the tank by gravity passes down through a delivery tube and through a restrictor to the nozzle, where it is atomised by the high velocity air from the fan unit. The whole idea behind mistblowing is to enable spray droplets to be projected to a much greater target than is normally achieved by the use of hydraulic nozzles. The droplets could go as far as 46 metres when they are of about 80 micron median diameter (Vmd), (Potts 1946), thus being capable of controlling tree crop pests in taller trees, such as in cocoa plantations in Ghana and Nigeria. Droplet sizes and distribution from these machines vary considerably with makes of the machines, even though operating conditions may be more or less similar. For example, five makes of these machines when tested revealed that under similar engine speeds and at same distances from their nozzles, water droplets obtained from them vary between 87 micron to well over 200 micron Vmd with dispersion ratios (r) of 1.30 to 2.06 (Kaul and Suleiman, 1980). Mistblowers could be adopted for ultra low volume (ULV) application by restricting the flow of liquid to the nozzle using appropriate interchangeable restrictors, and they could be used as dusters in addition to their usage as liquid applicators. Further development of these types of sprayers include tractor mounted or trailed, the central features of which include sprayer with centrifugal fan but air ducted along horizontal boom with nozzles at intervals along the boom. Studies on orchard spraying at the National Institute of Agricultural Engineering (NIAE) led to the development of another form of gaseous energy sprayer, the 'Commandair', producing air at a speed of 20.7 metres per second of $7.8 \text{ m}^3/\text{sec}$ for control of orchard pests (Matthews, 1979).

1.213 Thermal energy sprayers

Thermal energy sprayers are used for the control of pests mostly in enclosed spaces such as storage warehouses, greenhouses and farm sheds, unlike previous sprayers discussed that are used for control of field crop pests. In these machines pesticide, usually dissolved in an oil,

is injected into a hot gas and vaporised forming a dense fog by the condensation of the oil when discharge into the atmosphere. They are known as fogging machines and most of them produce droplets larger than 15 micron. Fogging is particularly useful for control of flying insects mostly due to fumigant effect of volatile pesticide.

1.214 Electrical energy sprayers

These are the most recently developed sprayers, the development of which appears to represent a major breakthrough in pesticide application technology. The central feature in these machines is the electrostatic charging of their formulations. Typical of these machines is the Imperial Chemical Industries' (ICI) 'Electrodyn Sprayer'. This uses a special ready-prepared formulation with electrical properties and contained in approximately $\frac{1}{2}$ litre bottle sealed with an annular nozzle, together called a 'Bozzle' (bottle plus nozzle), screwed to the main body of the sprayer. The power unit consists of 6 v U2 batteries, which operates a built-in generator capable of giving an output of about 25 000 v electric field around a ring which surrounds the annular nozzle. As the formulation is fed down by gravity from the 'Bozzle', it gets charged and disintegrates into very fine droplets of the order of 45 to 64 micron Vmd (IAR, 1982).

The whole idea behind charging of spray in this manner is improvement of droplet deposition efficiency. The use of smaller droplets to improve retention and coverage has been restricted due to fears of environmental contamination from drift, hence chemicals approved for controlled droplet application (CDA) must be applied in 250 micron droplets (CDA 250) (Heijne, 1980). With electrostatic charging of spray, drift can however be reduced since by charging the droplets they are attracted to the target. Several advantages seem apparent with the electrical energy sprayers. For example, the (ICI) Electrodyn is capable of applying pesticide at a very low application rate of 0.5 litre per hectare, when compared with conventional hydraulic nozzle applying 500 or more, especially in areas where water is a constraint. Power consumption test revealed that the Electrodyn consumes as low as 1.2% of the minimum power consumed by one of the spinning disc applicators, the 'Ulva' (IAR, 1982). Recent work at the

NIAE revealed the possibility of charging water based spray at much lower voltage, 2000 v, compared to ICI's oil based spray at much, much higher voltage, 25 000 v.

1.215 Centrifugal Energy Sprayers

A most promising method of controlling size of droplets within fairly narrow limits is by using centrifugal energy nozzles (eg spinning disc) with which droplet size can be adjusted by varying their rotational speed (Matthews, 1979). Centrifugal energy sprayers are used for ultra low volume (ULV) concept, the objective of which is to apply the minimum volume compatible with achieving economic control of the pest.

A hand-held spinning disc ULV sprayer usually has a plastic spray head with small electric motor which drives a rotating disc. Liquid is fed from about a litre capacity tank through a restrictor onto the surface of the rotating disc by gravity, so that centrifugal force spreads the liquid to the edge or near the edge of the disc where droplets are formed.

Another advantage of these sprayers over conventional types, apart from control of drop size within narrow limits, is the low application rate per hectare. About 2.5 litre per hectare is typical of application rate using some tested makes as against many hundreds with hydraulic energy nozzled sprayers (Kaul and Suleiman, 1980). In arid and semi-arid parts of the world where water may be a constraint, these types of machines have high potential of use.

1.2151 Types of spinning disc ultra low volume (ULV) sprayers

Two distinct classes of these machines are identified viz:

- a) Insecticide/fungicide applicators: These machines operate at very high rotation speeds and produce droplets that are very small, capable of controlling flying insects. Recent performance tests at the Overseas Spraying Machinery Centre (OSMC) revealed that at same flow rates (1.0 ml/s) using same formulation, four different makes of these machines

produced droplets of size ranges of 62 to 67 micron volume median diameter (Vmd), and dispersion ratios (r) of 1.18 to 1.35, with power consumption of 4.92 to 10.6 watt 12 volt. Another machine, 'Micron Micro-Ulva', at 0.5 m/s, produced 44 microns Vmd droplets, 1.6 (r) and 3.46 watt at 12 volt when operating at 16 000 rpm (Arnold, 1983).

b) Herbicide applicators: These machines operate at much lower speeds of rotation, about 1250 to around 9000 rpm (Cf to about 7500 to 16 000 rpm in the case of insecticide/fungicide applicators), producing much bigger droplet sizes. Bigger droplets are required in this case to avoid drift and to ensure placement of herbicides on weeds. About 250 micron Vmd is about typical, although some makes produce much bigger drops, up to 400 micron Vmd at 1.0 ml/s (Arnold, 1983).

1.22 Theory of Droplet Formation from a Rotating Disc

When liquid is fed onto a rotating disc, droplet forms and is released from the edge of the disc when the centrifugal force on the droplet overcomes the surface tension holding it there. Hinze and Milborn (1950) identified three essentially different types of liquid disintegration which may take place around and beyond the edge of a spinning disc, viz:

- (i) Direct droplet formation
- (ii) Ligament formation
- (iii) Sheet formation

Transition from one state to another was promoted by an increase in flow rate for a given disc, disc rotation speed.

1.221 Direct droplet formation

This is the first of the three states and occurs when a rotating disc is fed with liquid at low flow rates. In this case droplets of fairly uniform size are thrown directly from the edge of the disc and are called 'satellite' droplets. Walton and Prewett (1949) deduced the following expression for the diameter of droplets formed

in this way.

$$d = K \frac{1}{w} \sqrt{\frac{\gamma}{D\rho}}$$

- where d = droplet diameter in micron
- w = angular velocity (rad/sec)
- D = diameter of disc or cup (mm)
- γ = surface tension of liquid (MN/m)
- ρ = density of liquid (g/cm^{-3})
- K = constant

Formation of droplets in this way would have been most appreciated and useful were it not because of one chief problem. The maximum possible liquid flow rate is rather low for many practical applications, including use as ground crop sprayer. For example, the maximum flow rate using a simple 80 mm diameter disc to produce a 200 micron drop of water is about 0.3 ml/sec, beyond which rate the droplet size spectrum widens. This flow rate means that 33 discs per metre width of spraying machine would be required to apply only 50 litre per hectare at a forward speed of 2 m/s, assuming that all the output from each disc was used (Frost, 1978). The more recently developed 'Micron Herbi', which has serrated edged disc, has raised the limit on flow rate from the 0.3 ml/sec mentioned above to about 1.5 ml/sec. This however still means that $6\frac{2}{3}$ discs per metre width of spraying machine would be required to apply 50 litre per hectare at 2 ml/sec.

1.222 Ligament formation

This is the second main state of atomisation and occurs at flow rates higher than those in which direct droplets are formed. In this case liquid forms a ring around the disc edge from which long, curved threads or ligaments are produced. These ligaments become unstable and disintegrate into droplets at some distance from the disc.

1.223 Sheet formation

This is the third main state of atomisation from a spinning disc. In this case, a film of liquid on the surface of the disc extends beyond the disc periphery and breaks up in an irregular way. It occurs at flow rates higher than those in which ligaments are formed. Sheet formation occurs when the rotating surface is flooded and drop-let formation is similar to that with hydraulic nozzles with wide range of droplet sizes.

1.23 Disc Design

Early designs of ultra low volume spinning disc sprayers consist of double disc, one in front and the other at the rear. Two discs were used so that any liquid splashed from the rear of the front disc was collected and thrown off the rear disc. Initial designs concentrated mainly on smoothed-edged discs, but droplet sizes were found to reduce by 13% when a 45° chamber around the edge was made (Matthews, 1979).

It has been indicated that droplet formation is inversely proportional to angular velocity (ω) and an inverse square root function of disc diameter.

One factor however not correlated at that time was the issuing point of the spray liquid. Although different disc profiles do not provide appreciable difference in droplet formation, one feature of the disc which got considerable effect as explained by Bals(1970) is what is known as the 'longitudinal coefficient' of the disc circumference. Longitudinal coefficient is a three-dimensional factor which affects the coalescence of the liquid due to surface tension. This 'longitudinal coefficient' affects the tenacity of the liquid and a greater amount of force is necessary to break the droplet away from the disc surface. Bals further found that if one substitutes a needle point or 'zero issuing point', the break away of droplets from the surface requires correspondingly less force, or for a given force the droplet is smaller when it breaks away. This is the main point behind

making discs with serrated edges to provide 360 half-pyramidal, 'zero issuing points' since by doing so the force required to overcome surface tension is reduced.

Further work done on this led to the development of discs with grooved inner surface, but this was done simply to provide a reservoir of liquid to feed ligaments of spray liquid to individual issuing points around the periphery. A very narrow range of droplet sizes is produced with discs having both grooves and teeth, hence their suitability for the controlled droplet application (CDA).

1.24 Determination of droplet size

There are various techniques for measuring spray droplets. Unfortunately, there is no single precise method of measuring a wide range of droplet sizes. Four of the main techniques are:

- (1) Use of laser holography
- (2) Use of high speed photography
- (3) Use of microscope and graticule
- (4) Use of particle size analyser

Selection of any one technique for measurement of drop sizes depends upon many factors, such as availability of technique, ranges of droplet sizes to be measured, speed of measurement required, etc.

(1) The use of laser holography is one of the most sophisticated and accurate techniques which allows 3-dimensional study of the behaviour of small droplets as they impinge on insects (Matthews, 1975a), but has the limitation of being more particularly useful for measuring droplets in the 1 to 50 micron range.

(2) The use of high speed photography is another method used for the study of break up of liquid into droplets. Spray formation could be examined using short duration flash photography, giving exposures of less than one millionth of a second (Lake, 1979).

(3) The use of microscope fitted with a spray classification graticule (Matthews, 1975b) could be used to broadly classify droplets into the following categories: aerosols; mist; fine; medium; or coarse sprays when precise measurement is not necessary. A Porton G12 graticule is used when precise measurements are needed. A stage micrometer is needed to calibrate the graticule.

(4) When carrying out measurements of a large number of droplets, the use of graticule is laborious. An alternative method, which has been devised to increase speed and maintain accuracy, is the use of a Fleming particle size analyser type 526, now obtained from VER Electronics, Markyate, Herts, UK.

In this instrument, a vibrator unit is fitted between the eye-piece and the draw-tube of the microscope and operated electrically from a control unit, so that the image of the droplet is sheared. The control unit has ten channels (A-J), each of which can be calibrated to particular sizes. The instrument can be operated by switching the shear size between the chosen channel and the lower adjacent channel by using a step function, so that in a particular channel setting when a droplet alternately overlaps and separates its size lie between the two channel limits. The droplets are counted by operating a foot (as in the case of the College's particle size analyser) or hand-switch connected to 11 counters, one for each channel and to record the total number of droplets. The particle size analyser method is the most sophisticated method of which equipments are readily available to us at the College hence throughout this project, it was selected for droplet measurement.

CHAPTER II

PROJECT OBJECTIVE AND METHODOLOGY

2.1 Statement of Problem and Objective of Experimental Work

When a spinning disc ultra low volume sprayer is manufactured by an industry, it is usually subjected to different laboratory and field performance tests by that industry and/or by a spraying machinery centre, such as the Overseas Spraying Machinery Centre (OSMC) at Ascot here in the UK. The machine is then subsequently passed to a farmer within the locality or more likely to a tropical peasant farmer who has no engineering knowledge or technical skill of machine handling and maintenance. Thus, the machine is subject to different degrees of rough handling and misuse, such as:

- (a) Passing the rotating disc during spray through thick bushes, grasses or tough stem remnants of previous crop or weeds.
- (b) Subjecting the machine disc to formulation blockage of its surface as a result of lack of cleaning up of sprayer head after use.
- (c) Dropping the machine on the floor after return from spraying.
- (d) Subjecting the machine's plastic head to large range temperature - hot sun during the day and cool atmosphere during the night - that is by leaving the machine in the farm overnight.

Either of the above mishandlings of spinning disc machine could cause an instant disc damage or a faster disc deterioration than otherwise would be. Possible range of damages that might occur may include change of straightness of disc surface, blockage of disc grooves and edges with formulation, or damages of different degrees to the teeth of the disc. When a sharp point, a needle point, or a 'zero issuing point' is substituted in place of a blunt point of the edge of a spinning disc, the force required to atomise liquid into droplets is

less compared with that for a blunt surface or for a given force the droplets are smaller (Bals, 1970). By implication, this gives a likely indication of change in performance with disc condition, but what sort of changes in performance are likely to occur as a result of disc deterioration?

It is the objective of this work to examine performance changes which occur with tooth damage and surface groove clogging to a spinning disc atomiser, viz:

- changes in droplet spectrum
- the likely consequences in crop protection

2.2 Outline Methodology

1. Select a certain make of ultra low volume (ULV) spinning disc sprayer and determine the droplet spectrum produced by the rotating disc when emitting droplets at a constant travel speed and environmental condition.
2. Subject spinning discs to artificial damage of their teeth to varying degrees of severity.
3. Determine the droplet spectrum produced by each of the damaged discs under conditions that are as similar as possible to those conditions in 1. above.
4. Comparison between droplet spectra produced in steps 1. and 3. above.
5. Assess the likely consequences the obtained results could have on crop protection if any.

2.3 Selection of Spinning Disc

Among the different makes and models of ultra low volume spinning disc sprayers available in the market today, some of the most common makes used for the control of crop pests in Northern Nigeria are identified as follows:

- (a) 'Micron Ulva' and 'Micron Micro-Ulva' used for the application of insecticides and fungicides.
- (b) 'Micron Herbi' used for application of herbicides.
- (c) 'Turbair X' used for the application of insecticides and fungicides.

From literature the average droplet size produced by the 'Micron Ulva' is about 40 micron at 12 volt 0.33 ml/sec flow rate, and 15 000 rpm rotation speed as claimed by the manufacturer (Micron Sprayers).

'Micron Herbi', which is a herbicide applicator and designed to produce bigger droplets, is claimed by the manufacturer to be producing droplets of about 250 micron (Micron Sprayers, 1977). However, performance assessment carried out at the Overseas Spraying Machinery Centre revealed a higher droplet size of 290 micron (vmd) (OSMC, 1981).

'Turbair X' produces somewhat similar range of droplets as that of 'Micron Ulva' 64 micron (Vmd) at 12 volt and 7700 rpm (Kaul and Suleiman, 1980). Unlike Ulva, however, this machine is only recommended for use with special Turbair X ULV formulation of generally lower viscosity than that of conventional ULV formulations.

The most sophisticated equipment for the determination of droplet size parameters available to the College is the Fleming particle size analyser. This equipment under normal circumstances cannot be used to measure droplets greater than 250 microns. Therefore, the use of this

equipment to analyse drops produced by 'Micron Herbi' is almost impossible. Thus 'Micron Herbi' cannot be used for this investigation.

'Turbaire X' machine, whose droplet sizes fall to within measurable limits of the Fleming, is also rejected in this investigation due to restriction in the use of ultra low volume formulations.

'Micron Ulva' produces drops that fall also within the measurable limits of the Fleming, and could be used with any conventional ULV formulation, hence it is selected for this investigation.

2.4 Selection of Ultra Low Volume (ULV) Formulation

Since during the centrifugal atomisation from the spinning disc, small droplets are formed which are used to achieve effective coverage, evaporation of droplets needs to be minimised. Evaporation of drops depends upon meteorological factors such as temperature, relative humidity, wind speed etc. For example, a 100 micron droplet falling in still air at 20°C and 80% RH takes 50 seconds to extinct while the same droplet at 30°C and 50% RH takes only 14 seconds (Matthews, 1979). Hence ULV formulations should satisfy a number of requirements that take into account evaporation and ease of atomisation problems, viz:

- (1) Low volatility: Should not evaporate immediately after release as a droplet.
- (2) Low viscosity index: Not only should it flow easily through a tiny restrictor, but it should be capable of remaining at same viscosity range despite increase of temperature.
- (3) High specific gravity: In order to increase the terminal velocity of drops which enable contact with target immediately after release.

(5) Low surface tension: So that minimum force is required to atomise the liquid into droplets.

Unfortunately, there is no single (ideal) formulation that satisfies all of the above requirements, so some form of compromise has to be reached during selection. Most oil based sprays would satisfy requirements (1) and (5), but usually the choice of formulation is decided by what is readily available and the price of the formulation.

for this investigation the oil based formulation most readily available to us is the Turbair Permethrin ULV, and hence selected for the experimentation.

2.5 Definitions of Different Degrees of Artificial Damages

Three degrees of disc teeth damage and a disc groove clogging were identified as possible types of spinning disc deteriorations and defined as follows:

(1) Light teeth damage: Whereby one-third of the tips of a spinning disc is chopped off.

(2) Medium teeth damage: Whereby about two-thirds of teeth length is chopped off.

(3) Heavy teeth damage: Whereby all spinning disc teeth are chopped off.

(4) Disc groove clogging: Whereby the spinning disc grooves are blocked by chemicals such as wettable powder.

2.6 Treatments of spinning discs

The above types and degrees of damages were simulated on identical spinning discs of a 'Micron Micro Ulva' sprayer. On the whole, five identical spinning discs were used treated and labelled as follows:

(1) Disc L: On this disc, light damage was inflicted on its teeth by turning the disc on a lathe machine chopping off 0.33 mm out of its 1.0 mm long teeth.

(2) Disc M: On this disc, a medium damage was inflicted on its teeth by chopping 0.66 mm out of its 1.0 mm long teeth.

(3) Disc H: On this disc, a heavy damage was inflicted on its teeth by chopping off all of its teeth.

(4) Disc CL: On this disc, all grooves on the surface of the disc were blocked with wax to simulate chemical blockage of grooves, such as that possible when using a wettable powder.

(5) Disc C: Used as a control disc. There is no teeth damage or clogging of grooves on this disc.

The three degrees of teeth damages are illustrated diagrammatically on Figure 2.

CHAPTER III

APPROACH TO THE PROBLEM

3.1 Experimental Design

3.11 Randomisation

Here droplet samplings on magnesium oxide coated slides were allocated between treatments at random to avoid conscious or unconscious bias due to possible effects of changes of meteorological conditions, tiredness of the sprayer operator (even though this might to some extent be eliminated by the mechanical test rig) etc. Thus giving each treatment equal chances of good or bad droplet sampling. A completely randomised design was carried out. There were five treatments as described previously viz: Light (L); Medium (M); Heavy (H) teeth damages; Groove clogging (CL), and a control disc (C). Each was replicated three times, giving a total number of experimental droplet samples of (5 x 3) 15, so that in the design droplet sampling was allocated at random to the fifteen experiments.

3.12 Layout of the experiments

To satisfy the principle of randomisation, droplet samplings were numbered 1 to 15 and arranged so that a random selection of 3 of the numbers between 1 and 15 carry treatment (L), a further random selection of 3 of the numbers carry treatment (M), and so on.

The random selection was made using the table of random numbers (Lindley and Miller, 1970). In the layout of the completely randomised design with three replications of 5 treatments the available droplet samplings were numbered 1 to 15, then considering the pairs of random digits, viz 20, 17, 42, 28, 23, 17, 59, 66, 38, 61, etc, each of the above numbers was then divided by 15 if it is greater than it and the remainder regarded as an order of a sampling. Ignoring any repeated remainders and zero, a list of numbers between 1 and 15 arranged in random order were arrived as follows: 5, 2, 12, 13, 8, 14, 6, 1, 10, 11, 7, 4, 3, 9, and 15.

The 5th, 2nd and 12th droplet samplings were carried out using a spinning disc with the first treatment (Light damage).

The 13th, 8th and 14th droplet samplings were carried out using a spinning disc with the second treatment (Medium damage).

The 6th, 1st and 10th samplings with spinning disc with the third treatment (Heavy damage).

The 11th, 7th and 4th samplings with a spinning disc with the fourth treatment (Groove clogging).

Lastly, the 3rd, 9th and 15th samplings were carried out using a spinning disc with no treatment at all, ie the control disc.

The following order was therefore followed during droplet sampling:

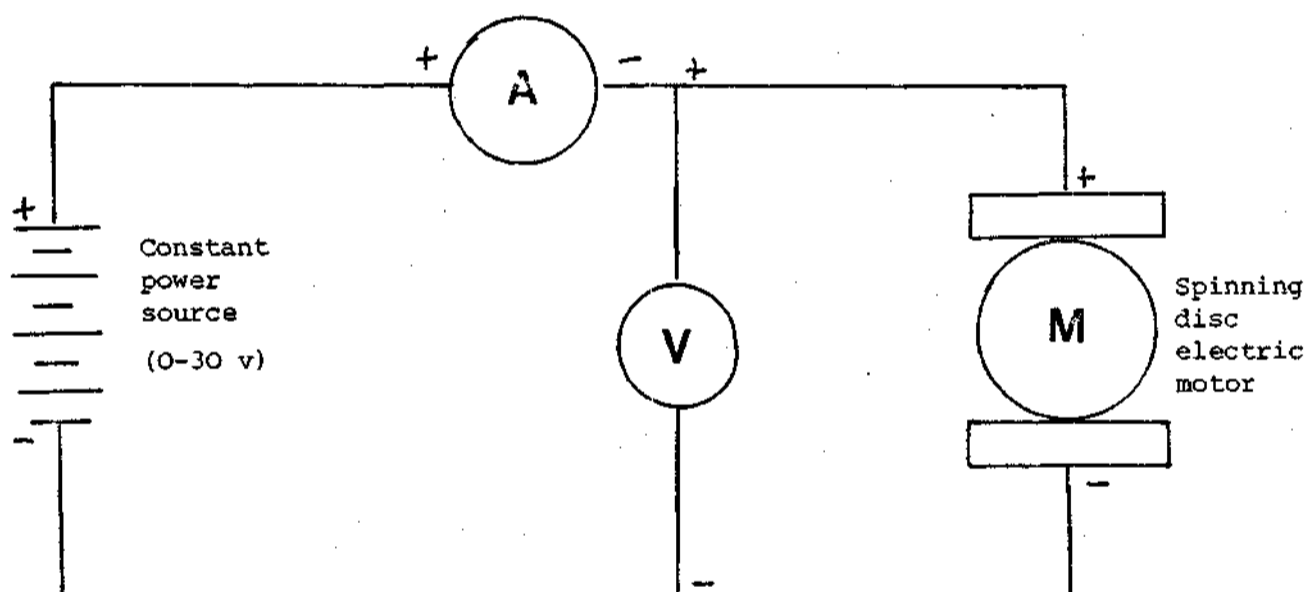
1st run	-	Use heavy damage disc
2nd "	-	" light damage disc
3rd "	-	" control disc
4th "	-	" clogged disc
5th "	-	" light damage disc
6th "	-	" heavy damage disc
7th "	-	" clogged disc
8th "	-	" medium damage disc
9th "	-	" control disc
10th "	-	" heavy damage disc
11th "	-	" clogged disc
12th "	-	" light damage disc
13th "	-	" medium damage disc
14th "	-	" medium damage disc
15th "	-	" control disc

Variation in power consumption of the spinning discs was suspected since Bals (1970) concluded that when a 'zero issuing point' is substituted in place of a blunt point as an edge of a spinning disc, the force required to atomise the liquid reduces. Conversely, it would be expected to

increase when a blunt point is substituted in place of a 'zero issuing point'.

Arrangement for measurement of power consumption was incorporated within the droplet sampling. Figure 3 illustrates the electrical circuit for the measurement of power consumed during the spray operation. An ammeter (A) was connected in series with the spinning disc electric motor and a constant power source (0-30 volt) DC set to operate at a constant voltage of 12 volt DC. A voltmeter was connected across the spinning disc motor, so that the voltage across the motor and the current the motor was using at any one time could be recorded.

Figure 3 - Circuit diagram for measurement of power consumption



3.2 Execution of Experiment

3.21 Droplet sampling procedure

Droplets were collected on magnesium oxide coated slides on which craters were formed by the impact of the droplets. The sampling surface was magnesium oxide, obtained by burning two strips of magnesium ribbon, each 10 cm in length, below a glass slide so that only the central area was coated uniformly. On impact with the magnesium oxide, the droplets formed craters which are 1.15 times larger than the true droplet sizes (May, 1950).

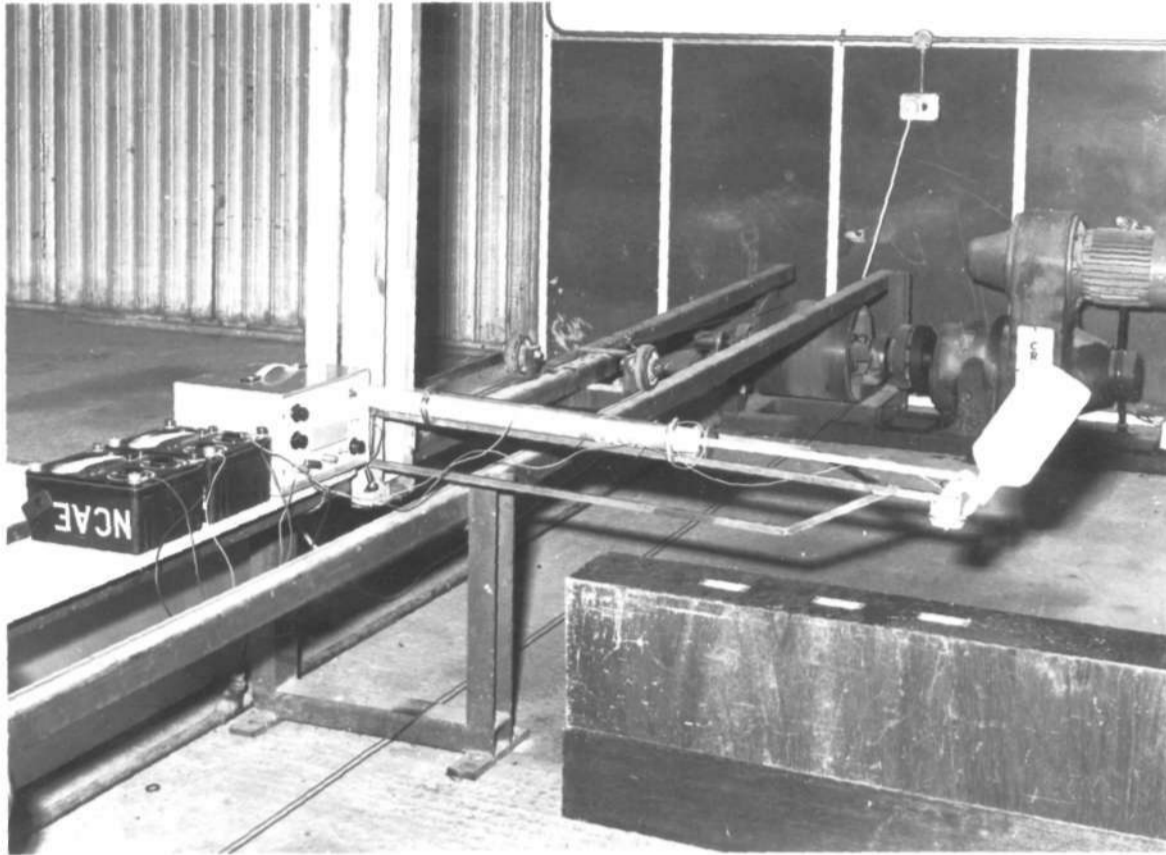
The difference in size between the crater and the true size of droplets is the spread factor whose reciprocal was used to convert the measurements of craters to true sizes. For magnesium oxide this factor is 0.86 (Matthews, 1979).

For each run of the experiments listed in the experimental design, two sampling surfaces were prepared as described above for droplets collection.

The droplet samples were obtained by operating a 'Micron Micro Ulva' spinning disc sprayer mounted on a spray head bracket, which was bolted to a mechanical test rig operated by an electric motor. The speed of the motor was adjusted so that the bracket carrying the spinning disc travelled at the forward speed of 1.0 metre/second (2.25 mph), which is the normal operating speed of the hand held spinning disc ULV sprayer.

Plate I illustrates the droplet sampling arrangement. The height of the spinning disc above the targets (the two MgO coated slides), the forward speed of the sprayer and the flow rate of the chosen formulation were maintained constant as 0.16 m, 1.0 m/s and 1.1 m/s respectively, in order to obtain repeatable droplet samplings

Plate I - Arrangement for spray droplets sampling



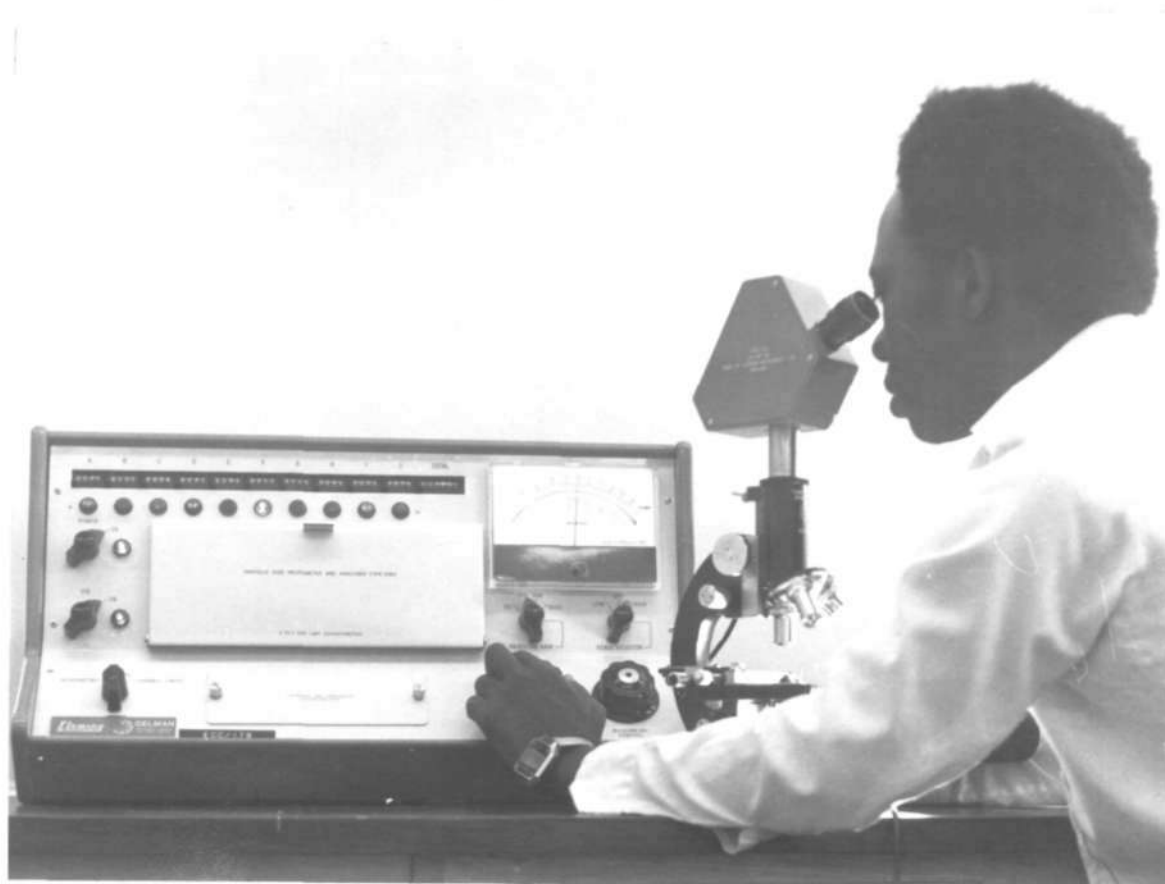
During droplet samples collection on magnesium oxide coated slides the sprayer was started and allowed to work under a constant voltage of 12 volt DC supplied by the constant power source for a short time until the current and voltage readings from the ammeter and voltmeter respectively remain constant. At that time, also the rotation speed remains constant at about 14500 rpm. The spray head bracket carrying the sprayer was operated at the set speed of 1.0 metre/second (2.25 mph) and the samples of droplets collected on the already laid glass slides below the spray head.

The random order set on page 19 was followed during droplet sampling and also during droplet measurements. The environmental temperature and wind speed were noted during sampling.

3.22 Droplet measurements

Droplet sizing of the samples collected was carried out using the Flemings Particle Size Analyser and a microscope according to the procedure laid down in Chapter I (page 11). The number of droplets from each class (channels) of the Particle Size Analyser were recorded for each of the fifteen runs of the experiment (N). Plate 2.

Plate 2 - Measurements of droplet size using the Flemings Particle Size Analyser



3.23 Droplet size analysis

Having obtained the number of droplets from each class (N), and the total number of droplets (SUM N), the percentage droplets (%N) for each class was calculated. The cumulative percentages (E%N) were calculated and plotted against the mean size (DM) on a logarithmic probability graph paper to obtain the number median diameter. The mean size was chosen because not all droplets in any particular size range are as large as the maximum for a given class.

As the volume of a sphere is $D^3/6$, and $/6$ is a common factor, the cube of the mean diameter was calculated (DM^3) and multiplied by the number of droplets in each class (NDM^3). These figures were then expressed as percentages of the total volume of the sample ($\%NDM^3$), and the cumulative percentages ($E\%NDM^3$) were plotted against the mean size (DM) on the same logarithmic probability graph paper to obtain the volume median diameter. The number median diameter (Nmd) and the volume median diameter (Vmd), were then read at the fifty percent intersect of the two graphs.

The above calculations, when done manually or using a simple electronic calculator, would be very laborious, time consuming and also a high chance of arithmetical errors exists. In order to speed up the process of data analysis, and to avoid the chances of arithmetical errors, particularly when dealing with a large number of droplet samples, a FORTRAN computer program was developed to calculate all the necessary droplet parameters required for obtaining the volume median diameter (Vmd), and the number median diameter (Nmd), given the number of droplets in each class as classified using the particle size analyser. The computer program developed is given in the Appendix I.

The computer program was run using the data obtained from each of the droplet samples and outputs of calculations required to obtain the Vmds and the Nmds were obtained. For each sample the graph of cumulative percentages was plotted against the mean droplet size and values of the Vmds and the Nmds read from the fifty percent intersect for the two graphs. The computer outputs and the graphs are given in Appendix II. The values of Vmds and the Nmds as obtained from the graphs are included in Table 1.

CHAPTER IV

ANALYSIS OF EXPERIMENTAL RESULTS

4.1 Summary of Experimental Results

Table 1 - Experimental Results

Disc treatment	Rotation speed (rpm)	Power consumption (Watt)	Vmd (micron)	Avr Vmd	Nmd (micron)	Avr Nmd	Dispersion ratio (r)	Avr (r)	V16 V84 N16 N84 (micron)			
									V16	V84	N16	N84
Light damaged	14 000	4.20	58		47		1.23		44	70	33	60
	14 000	4.08	57	57.67	45	46	1.26	1.25	40	66	31	58
	14 200	4.20	58		46		1.26		44	72	32	62
Medium damaged	14 300	3.30	55		44		1.25		41	68	31	60
	14 400	3.60	63	59.33	43	44	1.47	1.35	42	82	32	64
	14 400	3.60	60		45		1.35		48	70	34	62
Heavy damaged	14 400	4.20	64		53		1.20		50	74	37	68
	14 400	3.60	64	62.47	50	49.33	1.28	1.26	48	74	35	68
	14 300	3.60	60		45		1.30		44	70	33	62
Clogged	14 000	3.84	59		47		1.26		48	76	36	65
	14 500	3.84	63	60.67	45	46	1.40	1.32	45	80	33	62
	14 500	3.48	60		46		1.30		44	73	33	60
Control	14 500	3.00	48		40		1.20		38	59	28	51
	14 000	3.20	50	49.00	45	43	1.11	1.14	37	62	28	58
	14 000	3.00	49		44		1.11		39	62	32	59

The values of volume median diameters (Vmds), number median diameters (Nmds), dispersion ratios (r) and power consumptions mean very little without further statistical analysis, even though some apparent variations could be noticed within and between treatments.

A null hypothesis was established that there is no difference between each of the above measured quantities (Vmd), (Nmd), (r) and power consumption with disc damage. An analysis of variance was carried out for each of the above quantities to test the null hypothesis that there is no difference between the treatments. The total variation of the observations are partitioned into two components: One measuring the variability between the group means (eg 57, 67, 59, 33, 52, 47 etc for the (Vmd) values), and the other measuring the variation within each group (eg 55, 63, 60 for the medium damage (Vmd) values). The two components were compared by means of an F-Test.

The analysis of variance was carried out manually for each set of data and checked by running an existing analysis of variance programme with the college computer. The results are given in Tables 2-9.

4.2 Analysis of Variance

Analysis of variance for volume median diameter (Vmd)

For the volume median diameter, there were five treatments (C, L, M, H and CL), $t = 5$ and each replicated three times, $r = 3$. Let y be the volume median diameter in micron for the control disc (C), disc with light damage (L), disc with medium damage (M), disc with heavy damage (H), and disc with clogged grooves (CL).

Table 2 - Values of volume median diameters of droplet samples produced by differently treated spinning discs

Treatment	(Vmd)			Mean	
Control disc (C)	48	50	49	49	
Light damaged (L)	58	57	58	57.67	
Medium damaged (M)	55	63	60	59.33	
Heavy damaged (H)	64	64	60	62.67	Grand mean \bar{y}
Clogged (CL)	59	53	60	60.67	<u>57.87</u>

The total sum of squares:

$$\begin{aligned}
 S &= \sum y_i^2 - rt \bar{y}^2 && \dots \text{ (Chatfield, 1970)} \\
 &= 48^2 + 50^2 + 49^2 + 58^2 + \dots - 3 \times 5 \times (57.87^2) \\
 S &= \underline{383}
 \end{aligned}$$

The sum of squares due to difference between treatments:

$$\begin{aligned}
 St &= r \sum (y_i - \bar{y})^2 && \dots \text{ (Chatfield, 1970)} \\
 &= 3 \times (49^2 + 57.67^2 + 59.33^2 + \dots) - 3 \times 5 \times (57.87^2) \\
 St &= \underline{328.9}
 \end{aligned}$$

The analysis of variance table is as follows:

Table 3 - Table of analysis of variance for the Vmds

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Treatments	4	328.9	82.225	15.198
Residual	10	54.1	5.41	
Total	14	383.0	87.635	

If the null hypothesis is true, then F (treatment mean square/ residual mean square) has an F- distribution with (t-1) and (t(r-1)) degrees of freedom, in this case with 4 and 10 respectively.

For 5% significance we need $F > 5.96$ (Chatfield, C 1981). So, the null hypothesis of equal treatment means is rejected at the 5% level. That is, the treatment means are significantly different. It would be importance to know the least difference between disc treatments means which will be adjudged significant and therefore proceeded to calculate the Least Significant Difference as follows:

Least Significant Difference (LSD)

$$S^2 = 5.41, \quad r = 3, \quad \text{and } t_o = 2.228 \quad \text{(Chatfield, 1970)}$$

$$LSD = 2.228 \times \sqrt{\frac{2 \times 5.41}{3}}$$

$$LSD = \underline{4.23}$$

Control disc (C)	Light teeth damaged (L)	Medium teeth damaged (M)	Clogged grooves (CL)	Heavy teeth damaged (H)
49	57.67	59.33	60.67	62.67

Hence difference between treatments L and M, M and CL, CL and H are not significant. Also difference between treatments L and CL, and M and H are not significant. All others are significant at 5% level.

Analysis of variance for number median diameter (Nmd)

For the number median diameter, the same notations were used as for the volume median diameter and the data is tabulated below:

Table 4 - Number median diameter (Nmd) data

Treatment	(Nmd)			Mean
Control disc (C)	40	45	44	43
Light damaged (L)	47	45	46	46
Medium damaged (M)	44	43	45	44
Heavy damaged (H)	53	50	45	49.33
Clogged (CL)	47	45	46	46

Grand Mean: 45.67

The total sum of squares:

$$S = 118.76$$

The sum of squares due to differences between treatments:

$$St = 65.1132$$

The analysis of variance table is as follows:

Table 5 - Analysis of variance table for number median diameters

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Treatments	4	65.11	16.28	3.03
Residual	10	53.66	5.37	
Total	14	118.77	21.65	

For 5% significance we need $F > 5.96$, so the null hypothesis of equal treatment means is accepted at the 5% level. That is, the treatment means are not significantly different.

Analysis of variance for dispersion ratio (r)

The data for the dispersion ratios is tabulated below:

Table 6 - Values of dispersion ratios with different disc treatments

Treatment	(r) values			Mean
Control disc (C)	1.20	1.11	1.11	1.14
Light damaged (L)	1.23	1.26	1.26	1.25
Medium damaged (M)	1.25	1.47	1.33	1.35
Heavy damaged (H)	1.20	1.28	1.30	1.26
Clogged (CL)	1.26	1.40	1.30	1.32

Grand mean: 1.26

The total sum of squares:

$$S = 0.2766$$

The sum of squares due to differences between treatments;

$$St = 0.2298$$

The analysis of variance table is as follows:

Table 7 - Analysis of variance table for dispersion ratios (r)

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Treatments	4	0.2298	0.05745	12.2756
Residual	10	0.0468	0.00468	
Total	14	0.2766	0.06213	

For 5% significance we need $F > 5.96$. So the null hypothesis of equal treatment means is rejected at the 5% level. That is, the treatment means are significantly different.

Least Significant Difference (LSD)

$$s^2 = 0.00468, \quad r = 3, \quad t_o = 2.228$$

$$LSD = 2.228 \sqrt{\frac{2 \times 0.00468}{3}}$$

$$= \underline{0.1244}$$

Control' disc (C)	Light damaged (L)	Heavy damaged (H)	Clogged (CL)	Medium damaged (M)
1.14	1.25	1.26	1.32	1.35

From the values of LSD calculated, and the illustration above, differences between treatments (C) and (L), (L) and (H), (H) and (CL), (CL) and (M), (L) and (CL), and (H) and (M) are not significant. All others are significant at 5% level.

Analysis of variance for power consumption

The data for power consumption is tabulated below:

Table 8 - Power consumptions of differently treated discs

Treatment	Power consumption (Watt)			Mean
Control Disc (C)	3.00	3.20	3.00	3.07
Light damaged (L)	4.20	4.08	4.20	4.16
Medium damaged (M)	3.30	3.60	3.60	3.50
Heavy damaged (H)	4.20	3.60	3.60	3.80
Clogged (CL)	3.84	3.84	3.48	3.72

Grand Mean: 3.65

The total sum of squares:

$$S = 2.3005$$

The sum of squares due to difference between treatments:

$$St = 1.9392$$

The analysis of variance table is as follows:

Table 9 - Analysis of variance table for power consumption

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Treatments	4	1.9392	0.4848	13.4182
Residual	10	0.3613	0.03613	
Total	14	2.3005	0.52093	

For 5% significance we need $F > 5.96$. So the null hypothesis of equal treatment means is rejected at the 5% level, since our $F = 13.42$, ie (> 5.96). Therefore, the treatment means are significantly different. As in the previous similar cases, proceeded to calculate the least difference between treatment means which will be adjudged significant, as follows:

Least Significant Difference (LSD)

$$s^2 = 0.03613, \quad r = 3, \quad t_o = 2.228$$

$$LSD = 2.228 \sqrt{\frac{2 \times 0.03613}{3}}$$

$$LSD = 0.35$$

Control disc (C)	Medium damaged (M)	Clogged (CL)	Heavy damaged (H)	Light damaged (L)
3.07	3.50	3.72	3.80	4.16

This revealed that the differences between treatments (M) and (CL), (CL) and (H), and (M) and (H) are not significant. All others are significant at the 5% level.

CHAPTER V

GENERAL INFERENCES

5.1 Spinning Disc Damage and Spray Droplet Spectrum

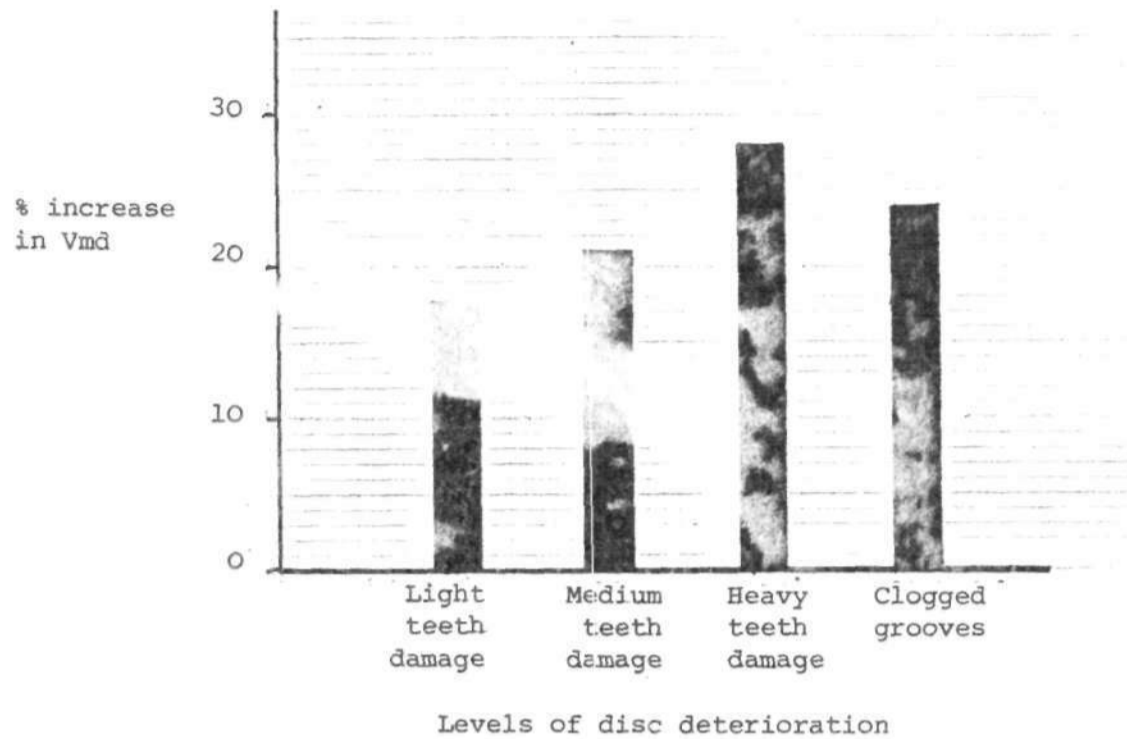
5.11 Effects of disc damage on volume median diameter (Vmd)

From the values of volume median diameter of droplet samples produced from the treated spinning discs and the control disc, the following deductions were made:-

- (a) There is a progressive increase of volume median diameter (Vmd) with severity of disc teeth damage. Up to 28% increase of Vmd was obtained when spinning disc was inflicted with heavy damage, (Fig. 4).
- (b) These increases were found to be significant, as revealed by the Least Significant Difference (LSD) values.
- (c) There was a significant increase in volume median diameter (Vmd) with spinning disc surface groove clogging. Up to about 24% increase of Vmd values in this case (Fig. 4).
- (d) A change from light to medium or medium to heavy damages does not significantly increase the Vmd, but an abrupt change from light to heavy damage does cause significant change in Vmd, as revealed by the LSD values.

In general, one would say that once teeth of an ultra low volume spinning disc sprayer are damaged, whether lightly, heavily or otherwise, the result would be an increase in droplet sizes. Also, when grooves of disc are blocked by chemicals, such as wettable powder, an increase in droplet size would be expected to occur.

Fig. 4 - Relationship between disc deterioration and volume median diameter (Vmd)



5.12 Disc damage and number median diameter (Nmd)

The data on number median diameter of the differently treated spinning discs and the analysis of variance of the data are given in Tables 4 and 5. Even though some variations of Nmd within and between treatments could be noticed, these differences are not significant as revealed by the acceptance of the null hypothesis ($F = 5.96$). This means that damages to spinning disc teeth of an ultra low volume sprayer has no significant effect on average droplet size.

Hence whether the disc teeth are lightly or severely damaged, or its grooves blocked by chemical, its average droplet size does not change significantly even though its droplet size increases.

5.13 Effects of disc damage on dispersion ratio (r)

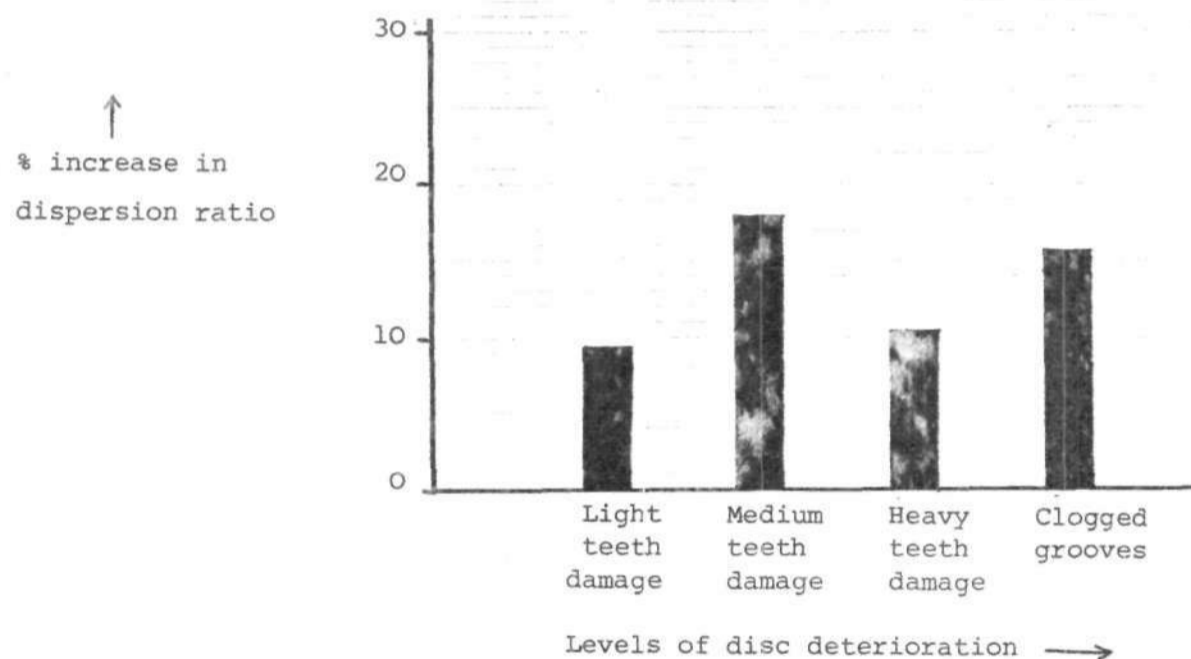
Dispersion ratio (r), as explained earlier, expresses the measure of uniformity of spray droplets. It indicates how wide or narrow the spectrum of droplets is. The closer this ratio is to unity, the

narrower the droplet spectrum, hence the higher the degree of uniformity of droplets.

Analysis of variance carried out on data of dispersion ratios revealed that there are significant increases of (r) values with disc teeth damage and with surface groove clogging. It is particularly interesting to note that even though the (r) values change damage of teeth, they do not change significantly until damages of teeth begin to be severe. That is, there is no significant increase in (r) values between undamaged disc and lightly damaged one, but there is between the former and the medium and or heavy damaged disc.

On the whole, as long as spinning disc teeth are slightly damaged, the droplet size increases but remains rather uniform up to a certain degree of damage when droplets begin to decrease in uniformity. Up to 18% increase in (r) value was recorded with medium teeth damage (Fig. 5).

Fig. 5 - Increase in dispersion ratio (r) with level of disc deterioration



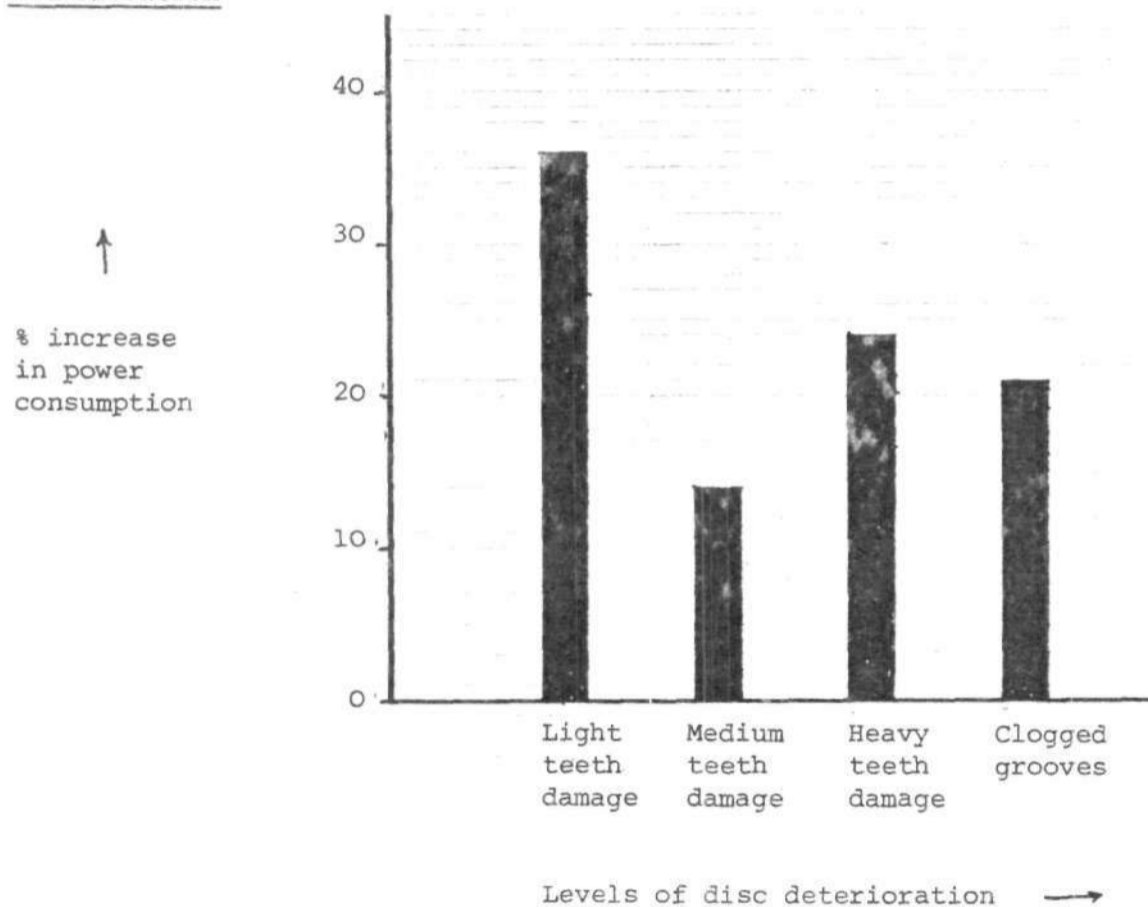
5.14 Effects of disc damage on power consumption

Values of power consumption with varying degrees of disc damages and analysis of variance of the values are presented in Tables 8 and 9 respectively.

Results of the analysis of variance revealed that there are significant increases of power consumption with certain degrees of disc damages and also with clogging of grooves of disc surface.

A point worthy of notice here is that as revealed by the recorded data and the analysis, even though teeth damage results in increase power consumption of the sprayer, it is the light teeth damage that results in the greatest power consumption rather than probably the expected heavy damage. Power consumption increase of up to 36% was recorded light teeth damage of the spinning disc (Fig. 6).

Fig. 6 - Increase in power consumption with level of spinning disc deterioration



5.2 Consequences of Spinning Disc Deterioration on Crop Protection

5.21 Consequences of increase of volume median diameter (Vmd)

Losses of pesticide

Volume median diameter of spray droplets is a measure of drop size in relation to volume of chemical applied. Power consumption of the spinning disc sprayer significantly increases with disc deterioration in general and more significantly with light teeth damage. Increase in Vmd may result in serious chemical loss due to run off if droplets are too big. This would be reflected in the volume of chemical being applied per unit area, which would in turn be reflected in the cost of chemical application per unit area. Consequently, disc teeth damage and/or surface groove clogging would be expected to result in uneconomical chemical application due to possible losses.

Environmental pollution

Not only losses due to run off of chemical results from too large droplet sizes, but also greater environmental pollution. The higher the run off, the higher the chances of pollution of environment. Lives of certain advantageous soil fauna, responsible for improving soil structure, such as worms might be affected by greater chemical residues due to pollution.

Ineffective pest control

When controlling flying insects we need droplets that are small enough to remain in suspension in the target environment for sufficient length of time to enable the flying insects to come into contact with them. If, however, the droplets increase in size due to disc deterioration, then this suspension ability is lost and effectiveness of control of flying insects is decreased. Retention also decreases when droplets are too big.

Phytotoxicity

Phytotoxic burns on plants leaves result when droplets are too big. Phytotoxic effects may be caused by chemical burning, physically by

droplets on the plant surface acting as lenses and focus the sun's rays on the plant tissue, or by subsequent effects on plant growth (Matthews, 1979). Thus increase in Vmd as a result of disc teeth damage could cause phytotoxic burns.

5.22 Consequences of increase in dispersion ratio (r)

Dispersion ratio was found to increase with teeth damage on a spinning disc. Also the ratio was found to increase with clogging of disc grooves. With damage, therefore, a wider range of droplets from the spinning disc results especially after serious damage is inflicted on teeth. This wide range of drops would result in losses either due to drift or run off or both, thus reducing efficiency of spray application.

5.23 Consequences of increase in power consumption due to spinning disc deterioration

Power consumption of spinning disc is one of the main factors which a farmer is most concerned with during chemical application with an ultra low volume sprayer, particularly in situations whereby dry cell batteries are used with those machines.

Power consumption was found to increase with disc damage, and interestingly more with lighter rather than severer teeth damage. Increase in power consumption means increase in running cost of the spinning disc sprayer by way of frequent replacement of batteries. Increase in running cost means uneconomical pesticide application in the long run. Power consumption increases by up to 36% with light teeth damage, and this would be expected to reflect battery cost.

CONCLUSIONS

The results of this investigation show that the droplet sizes progressively increase as the spinning disc teeth get more and more damaged. This was indicated by the significantly higher values of volume median diameters obtained (Tables 2 and 3). Droplet sizes were also found to increase when spinning disc surface grooves are blocked.

The average droplet size, however, remains more or less constant irrespective of degree of disc deterioration, as indicated by the fairly constant number median diameters (Tables 4 and 5).

The spray droplets were found to get less uniform with both disc teeth damage and also with surface groove clogging. This was indicated by higher values of dispersion ratios (r) in both cases (Tables 6 and 7), which indicates wider droplet spectra.

It was also found that power consumption of the spinning disc sprayer significantly increases with disc deterioration in general and more significantly with light teeth damage.

APPENDIX 1

Computer program for calculations required to determine the Volume median diameter (Vmd), and the Number median diameter (Nmd).

C. THIS PROGRAM CALCULATES AMONG OTHER DROPLET PARAMETERS,
 C. THE CUMULATIVE PERCENTAGE BY NUMBER (EXN) AND BY VOLUME (EXNDM**3)
 C. OF DROPLETS FROM EACH SIZE CLASS (D) WHICH WHEN PLOTTED AGAINST
 C. THE MEANSIZE (DM) (ALSO CALCULATED), PRODUCES CURVES FROM WHICH
 C. THE NUMBER MEDIUM DIAMETER (NMD), THE VOLUME MEDIUM DIAMETER (VMD)
 C. AND THE DISPERSION RATIO (R), COULD BE OBTAINED, GIVEN THE APPROPRIATE
 C. DATA FROM A SPRAY DROPLET SAMPLE.
 C. THE DROPLET SAMPLE COLLECTING SURFACE IS MAGNESIUM OXIDE COATED SLIDE.

```

8 DIMENSION D(10),N(10),DT(10),DM(10),PERN(10),CUPERN(10)
9 DIMENSION DMCUB(10),NDMCUB(10),PERNDC(10),SPRNDC(10)
10 WRITE (6,500)
11 500 FORMAT(1H1 ,115(1H-))
12 WRITE (6,100)
13 100FORMAT(1H ,5X,'UPPER',5X,'TRUE SIZE',3X,'MEAN',5X,'NUMBER',
+3X,'ZN',6X,'EXN',
+8X,'DM**3',9X,'NDM**3',10X,'ZNDM**3',5X,'EXNDM**3',/6X,
+'CLASS',6X,'UPPER',6X,'SIZE',4X,'IN CLASS'/7X,
+'SIZE',7X,'LIMIT',5X,'(DM)',6X,'(N)'/7X,'(D)',
+8X,'(DT)')
19 WRITE (6,700)
20 700 FORMAT(1H ,115(1H-))
21 DO 20 I=1,10
22 20 INPUT D(I),N(I)
23 SUMN=0
24 DO 30 I=1,10
25 30 SUM N=SUMN+N(I)
26 I=1
27 CUPERN(1)=0
28 SPRNDC(1)=0
29 DT(I)=D(I)*0.86
30 WRITE (6,200) D(1),DT(1)
31 200 FORMAT (F10.2,F12.2)
32 SUMNDC=0
33 40 DT(I+1)=D(I+1)*0.86
34 DM(I+1)=(DT(I)+DT(I+1))/2
35 PERN(I+1)=(N(I+1)/SUMN)*100
36 CUPERN(I+1)=PERN(I+1)+CUPERN(I)
37 DMCUB(I+1)=DM(I+1)**3
38 NDMCUB(I+1)=DMCUB(I+1)*N(I+1)
39 SUMNDC=SUMNDC+NDMCUB(I+1)
40 IF (I.EQ.9)GOTO 50
41 I=I+1
42 GO TO 40
43 50 SPRNDC(1)=0
44 DO 60 I=2,10
45 PERNDC(I)=(NDMCUB(I)/SUMNDC)*100
46 SPRNDC(I)=PERNDC(I)+SPRNDC(I-1)
47 60 WRITE (6,300) D(I),DT(I),DM(I),N(I),PERN(I),CUPERN(I),
+DMCUB(I),NDMCUB(I),PERNDC(I),SPRNDC(I)
49 300 FORMAT(F10.2,F12.2,F10.2,F10.2,F18.2,F8.2,F16.2,F17.2,F10.2,F12.2)
50 WRITE(6,800)
51 800 FORMAT(1H ,115(1H-))
52 WRITE(6,400) SUMN,SUMNDC
53 400 FORMAT (31X,'TOTAL:',14,27X,'TOTAL',F18.2)
54 WRITE (6,600)
55 600 FORMAT(31X,10('/-'),27X,22('/-'))
56 STOP
57 END

```

APPENDIX II
 Computer output of calculations required to determine the Volume median diameter (Vmd) and the Number median diameter (Nmd).

(L) I

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DN**3	NDM**3	XNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	9	3.00	3.00	9938.37	89445.00	0.19	0.19
40.00	34.40	30.10	27	9.00	12.00	27270.90	736314.00	1.59	1.78
50.00	43.00	38.70	57	19.00	31.00	57960.60	3303754.00	7.11	8.89
60.00	51.60	47.30	68	22.67	53.67	105823.82	7196019.00	15.49	24.38
70.00	60.20	55.90	70	23.33	77.00	174676.88	12227381.00	26.32	50.70
80.00	68.80	64.50	42	14.00	91.00	268336.12	11270117.00	24.26	74.96
90.00	77.40	73.10	20	6.67	97.67	390617.89	2812357.00	16.82	91.78
100.00	86.00	81.70	7	2.33	100.00	545338.51	3817369.00	8.22	100.00
TOTAL: 300						TOTAL	46452756.00		

(L) II

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DN**3	NDM**3	XNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	1	0.33	0.33	2146.69	2146.00	0.00	0.00
30.00	25.80	21.50	14	4.67	5.00	9938.37	139137.00	0.32	0.33
40.00	34.40	30.10	28	9.33	14.33	27270.90	763585.00	1.76	2.08
50.00	43.00	38.70	70	23.33	37.67	57960.60	4057242.00	9.34	11.42
60.00	51.60	47.30	55	18.33	56.00	105823.82	5820309.00	13.39	24.81
70.00	60.20	55.90	70	23.33	79.33	174676.88	12227381.00	28.14	52.95
80.00	68.80	64.50	41	13.67	93.00	268336.12	11001781.00	25.32	78.27
90.00	77.40	73.10	13	4.33	97.33	390617.89	5078032.00	11.69	89.96
100.00	86.00	81.70	8	2.67	100.00	545338.51	4362708.00	10.04	100.00
TOTAL: 300						TOTAL	43452321.00		

(L) III

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DN**3	NDM**3	XNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	2	0.67	0.67	2146.69	4293.00	0.01	0.01
30.00	25.80	21.50	6	2.00	2.67	9938.37	59630.00	0.12	0.13
40.00	34.40	30.10	33	11.00	13.67	27270.90	899939.00	1.83	1.96
50.00	43.00	38.70	71	23.67	37.33	57960.60	4115202.00	8.38	10.34
60.00	51.60	47.30	49	16.33	53.67	105823.82	5185367.00	10.55	20.89
70.00	60.20	55.90	55	18.33	72.00	174676.88	9607228.00	19.55	40.44
80.00	68.80	64.50	48	16.00	88.00	268336.12	12880133.00	26.21	66.66
90.00	77.40	73.10	21	7.00	95.00	390617.89	8202975.00	16.69	83.35
100.00	86.00	81.70	15	5.00	100.00	545338.51	8180077.00	16.65	100.00
TOTAL: 300						TOTAL	49134844.00		

(M) I

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NUM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	7	2.33	2.33	9938.37	69568.00	0.16	0.16
40.00	34.40	30.10	30	10.00	12.33	27270.90	818127.00	1.83	1.98
50.00	43.00	38.70	73	24.33	36.67	57960.60	4231124.00	9.45	11.43
60.00	51.60	47.30	67	22.33	59.00	105823.82	7090195.00	15.83	27.26
70.00	60.20	55.90	59	19.67	78.67	174676.88	10305935.00	23.01	50.27
80.00	68.80	64.50	40	13.33	92.00	268336.12	10733444.00	23.96	74.23
90.00	77.40	73.10	10	3.33	95.33	390617.89	3906178.00	8.72	82.95
100.00	86.00	81.70	14	4.67	100.00	545338.51	7634739.00	17.05	100.00
TOTAL: 300						TOTAL 44789310.00			

(M) II

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (BT)	MEAN SIZE (BM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NUM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	8	2.67	2.67	9938.37	79506.00	0.16	0.16
40.00	34.40	30.10	31	10.33	13.00	27270.90	845397.00	1.73	1.89
50.00	43.00	38.70	83	27.67	40.67	57960.60	4810730.00	9.82	11.71
60.00	51.60	47.30	74	24.67	65.33	105823.82	7830962.00	15.99	27.69
70.00	60.20	55.90	32	10.67	76.00	174676.88	5589660.00	11.41	39.10
80.00	68.80	64.50	24	8.00	84.00	268336.12	6440066.00	13.15	52.25
90.00	77.40	73.10	18	6.00	90.00	390617.89	7031122.00	14.35	66.60
100.00	86.00	81.70	30	10.00	100.00	545338.51	16360155.00	33.40	100.00
TOTAL: 300						TOTAL 48987598.00			

(M) III

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NUM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	4	1.33	1.33	9938.37	39753.00	0.08	0.08
40.00	34.40	30.10	12	4.00	5.33	27270.90	327250.00	0.65	0.73
50.00	43.00	38.70	73	24.33	29.67	57960.60	4231124.00	8.43	9.16
60.00	51.60	47.30	62	20.67	50.33	105823.82	6561076.00	13.07	22.23
70.00	60.20	55.90	79	26.33	76.67	174676.88	13799473.00	27.50	49.73
80.00	68.80	64.50	35	11.67	88.33	268336.12	9391764.00	18.71	68.44
90.00	77.40	73.10	21	7.00	95.33	390617.89	8202975.00	16.34	84.79
100.00	86.00	81.70	14	4.67	100.00	545338.51	7634739.00	15.21	100.00
TOTAL: 300						TOTAL 50188154.00			

(H) I

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	4	1.33	1.33	9938.37	39753.00	0.06	0.06
40.00	34.40	30.10	19	6.33	7.67	27270.90	518147.00	0.82	0.88
50.00	43.00	38.70	48	16.00	23.67	57960.60	2782108.00	4.39	5.27
60.00	51.60	47.30	46	15.33	39.00	105823.82	4867895.00	7.69	12.96
70.00	60.20	55.90	48	16.00	55.00	174676.88	8384490.00	13.24	26.20
80.00	68.80	64.50	73	24.33	79.33	268336.12	19588537.00	30.93	57.12
90.00	77.40	73.10	43	14.33	93.67	390617.89	16796569.00	26.52	83.64
100.00	86.00	81.70	19	6.33	100.00	545338.51	10361431.00	16.36	100.00
TOTAL: 300						TOTAL 63338930.00			

(H) II

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	1	0.33	0.33	2146.69	2146.00	0.00	0.00
30.00	25.80	21.50	4	1.33	1.67	9938.37	39753.00	0.06	0.07
40.00	34.40	30.10	15	5.00	6.67	27270.90	409063.00	0.64	0.71
50.00	43.00	38.70	53	17.67	24.33	57960.60	3071911.00	4.84	5.55
60.00	51.60	47.30	58	19.33	43.67	105823.82	6137781.00	9.67	15.23
70.00	60.20	55.90	49	16.33	60.00	174676.88	8559167.00	13.49	28.72
80.00	68.80	64.50	59	19.67	79.67	268336.12	15831831.00	24.95	53.67
90.00	77.40	73.10	25	8.33	88.00	390617.89	9765447.00	15.39	69.06
100.00	86.00	81.70	36	12.00	100.00	545338.51	19632186.00	30.94	100.00
TOTAL: 300						TOTAL 63449285.00			

(H) III

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	5	1.67	1.67	9938.37	49691.00	0.11	0.11
40.00	34.40	30.10	36	12.00	13.67	27270.90	981752.00	2.11	2.21
50.00	43.00	38.70	66	22.00	35.67	57960.60	3825399.00	8.20	10.42
60.00	51.60	47.30	60	20.00	55.67	105823.82	6349429.00	13.62	24.03
70.00	60.20	55.90	66	22.00	77.67	174676.88	11528674.00	24.72	48.76
80.00	68.80	64.50	30	10.00	87.67	268336.12	8050083.00	17.26	66.02
90.00	77.40	73.10	28	9.33	97.00	390617.89	10937300.00	23.46	89.47
100.00	86.00	81.70	9	3.00	100.00	545338.51	4908046.00	10.53	100.00
TOTAL: 300						TOTAL 46630374.00			

(CL)I

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NDM**3	ZNDM**3	EXNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	4	1.33	1.33	9938.37	39753.00	0.07	0.07
40.00	34.40	30.10	22	7.33	8.67	27270.90	599959.00	1.10	1.18
50.00	43.00	38.70	61	20.33	29.00	57960.60	3535596.00	6.50	7.67
60.00	51.60	47.30	65	21.67	50.67	105823.82	6878548.00	12.64	20.31
70.00	60.20	55.90	63	21.00	71.67	174676.88	11004643.00	20.22	40.54
80.00	68.80	64.50	36	12.00	83.67	268336.12	9660100.00	17.75	58.29
90.00	77.40	73.10	26	8.67	92.33	390617.89	10156065.00	18.66	76.95
100.00	86.00	81.70	23	7.67	100.00	545338.51	12542785.00	23.05	100.00
TOTAL: 300						TOTAL		54417449.00	

(CL)II

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NDM**3	ZNDM**3	EXNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	8	2.67	2.67	9938.37	79506.00	0.15	0.15
40.00	34.40	30.10	24	8.00	10.67	27270.90	654501.00	1.20	1.35
50.00	43.00	38.70	78	26.00	36.67	57960.60	4520927.00	8.31	9.66
60.00	51.60	47.30	58	19.33	56.00	105823.82	6137781.00	11.28	20.94
70.00	60.20	55.90	32	10.67	66.67	174676.88	5589660.00	10.27	31.21
80.00	68.80	64.50	50	16.67	83.33	268336.12	13416806.00	24.66	55.86
90.00	77.40	73.10	21	7.00	90.33	390617.89	8202975.00	15.07	70.94
100.00	86.00	81.70	29	9.67	100.00	545338.51	15814816.00	29.06	100.00
TOTAL: 300						TOTAL		54416972.00	

(CL)III

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EXN	DM**3	NDM**3	ZNDM**3	EXNDM**3
10.00	8.60								
20.00	17.20	12.90	4	1.33	1.33	2146.69	8586.00	0.02	0.02
30.00	25.80	21.50	8	2.67	4.00	9938.37	79506.00	0.17	0.19
40.00	34.40	30.10	18	6.00	10.00	27270.90	490876.00	1.04	1.23
50.00	43.00	38.70	58	19.33	29.33	57960.60	3361714.00	7.14	8.37
60.00	51.60	47.30	87	29.00	58.33	105823.82	9206672.00	19.55	27.92
70.00	60.20	55.90	66	22.00	80.33	174676.88	11528674.00	24.49	52.41
80.00	68.80	64.50	28	9.33	89.67	268336.12	7513411.00	15.96	68.37
90.00	77.40	73.10	13	4.33	94.00	390617.89	5078032.00	10.79	79.15
100.00	86.00	81.70	18	6.00	100.00	545338.51	9816093.00	20.85	100.00
TOTAL: 300						TOTAL		47083564.00	

(C) I

UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	21	7.00	7.00	9938.37	208705.00	0.70	0.70
40.00	34.40	30.10	40	13.33	20.33	27270.90	1090836.00	3.65	4.35
50.00	43.00	38.70	90	30.00	50.33	57960.60	5216454.00	17.45	21.80
60.00	51.60	47.30	76	25.33	75.67	105823.82	8042610.00	26.91	48.71
70.00	60.20	55.90	52	17.33	93.00	174676.88	9083197.00	30.39	79.10
80.00	68.80	64.50	16	5.33	98.33	268336.12	4293377.00	14.36	93.47
90.00	77.40	73.10	5	1.67	100.00	390617.89	1953089.00	6.53	100.00
100.00	86.00	81.70	0	0.	100.00	545338.51	0.	0.	100.00
TOTAL: 300						TOTAL 29888268.00			

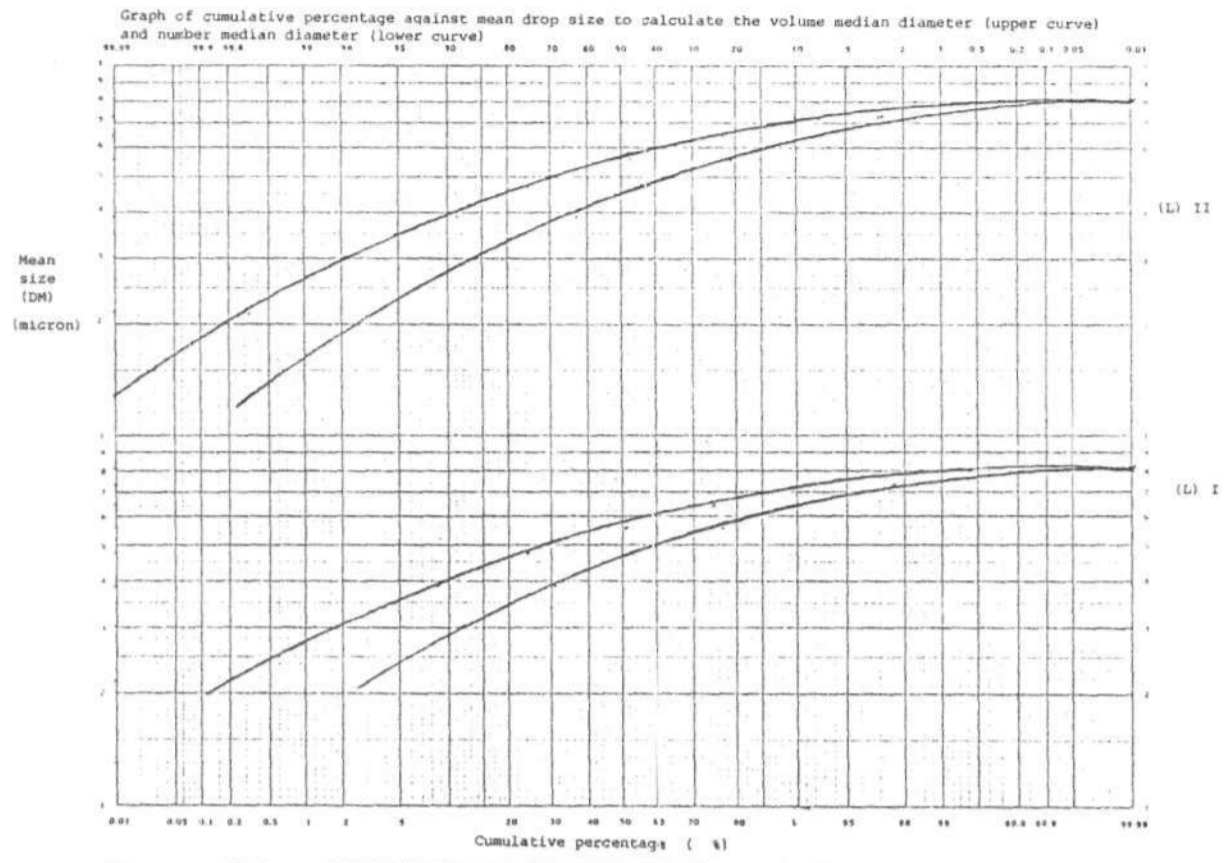
(C) II

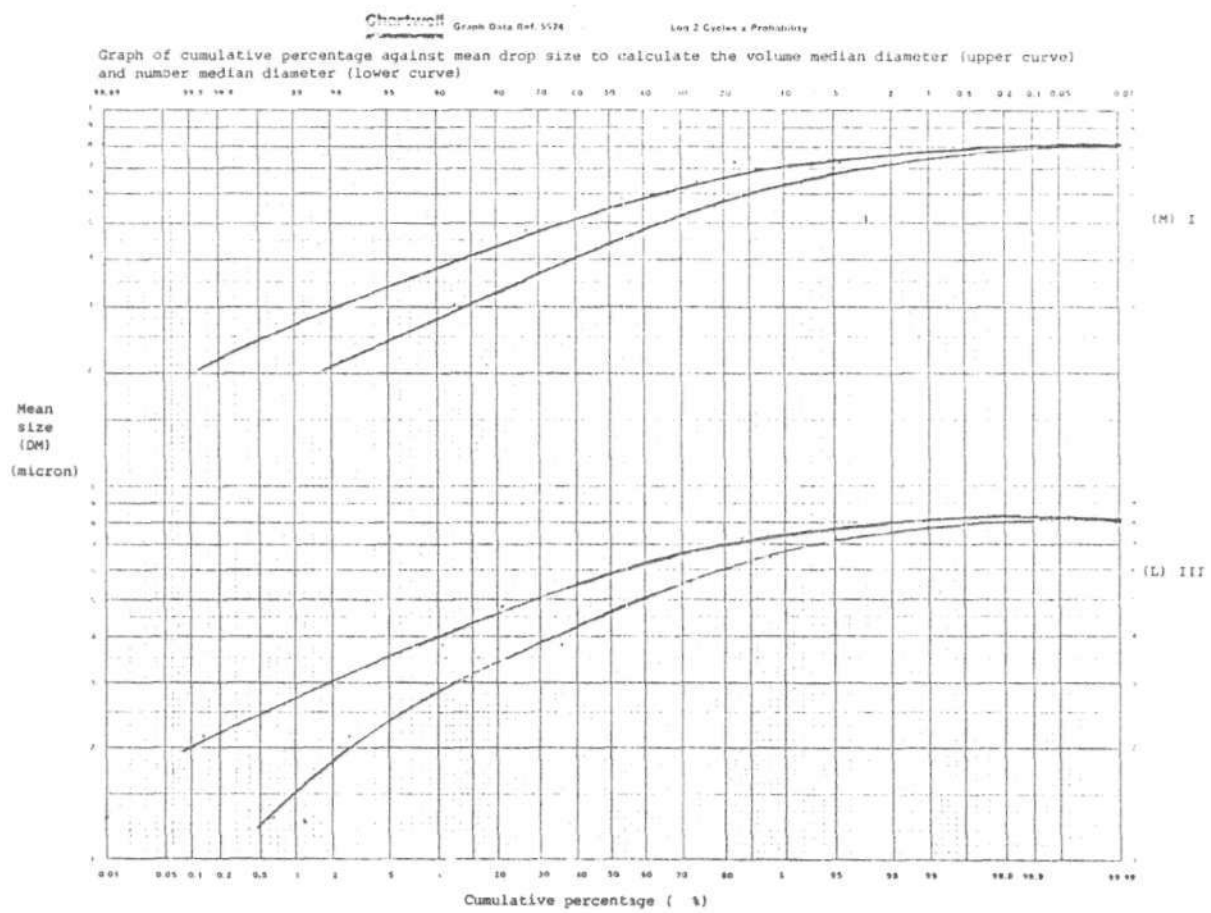
UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	1	0.33	0.33	2146.69	2146.00	0.01	0.01
30.00	25.80	21.50	17	5.67	6.00	9938.37	168952.00	0.40	0.40
40.00	34.40	30.10	43	14.33	20.33	27270.90	1172648.00	2.77	3.18
50.00	43.00	38.70	66	22.00	42.33	57960.60	3825399.00	9.04	12.22
60.00	51.60	47.30	51	17.00	59.33	105823.82	5397014.00	12.75	24.97
70.00	60.20	55.90	57	19.00	78.33	174676.88	9956582.00	23.53	48.50
80.00	68.80	64.50	37	12.33	90.67	268336.12	9928436.00	23.46	71.96
90.00	77.40	73.10	22	7.33	98.00	390617.89	8593593.00	20.31	92.27
100.00	86.00	81.70	6	2.00	100.00	545338.51	3272031.00	7.73	100.00
TOTAL: 300						TOTAL 42316801.00			

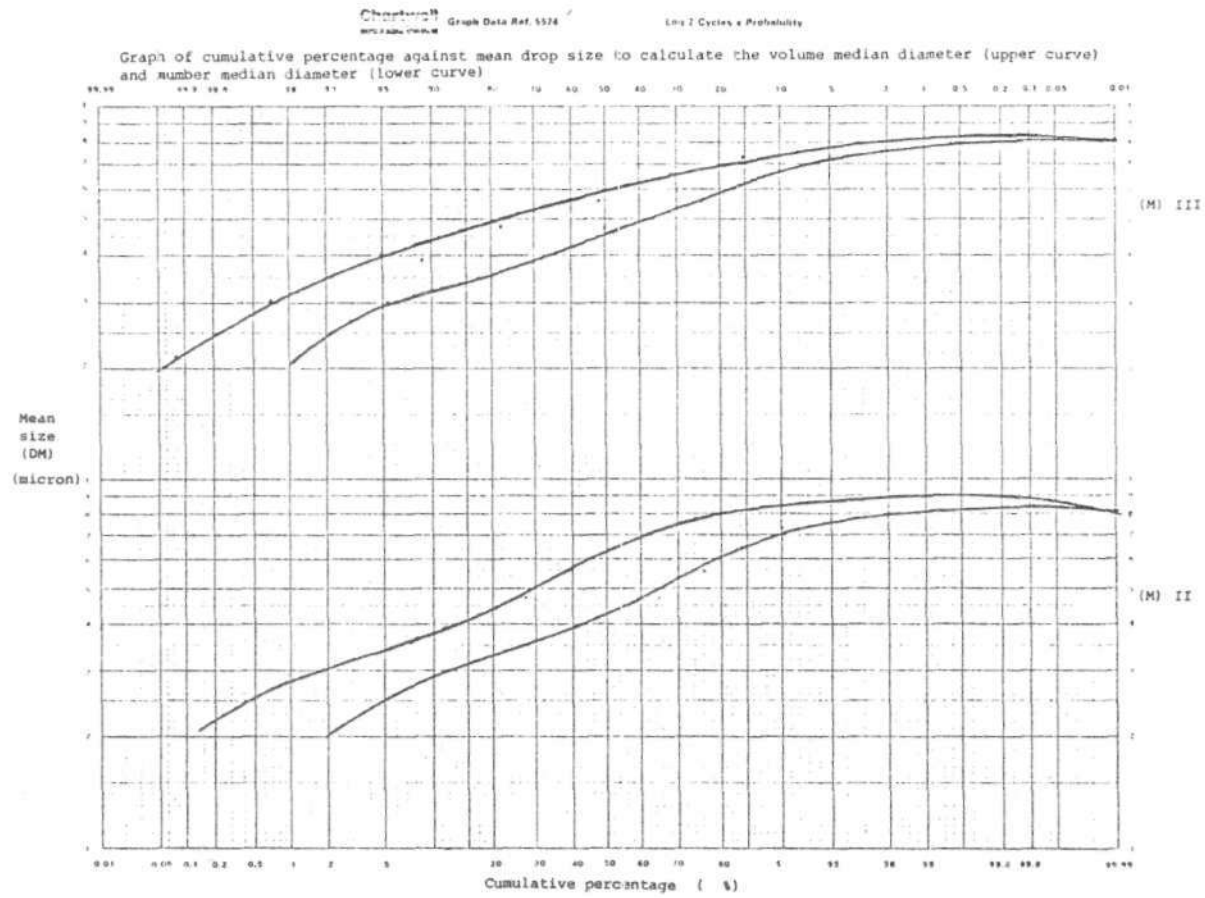
(C) III

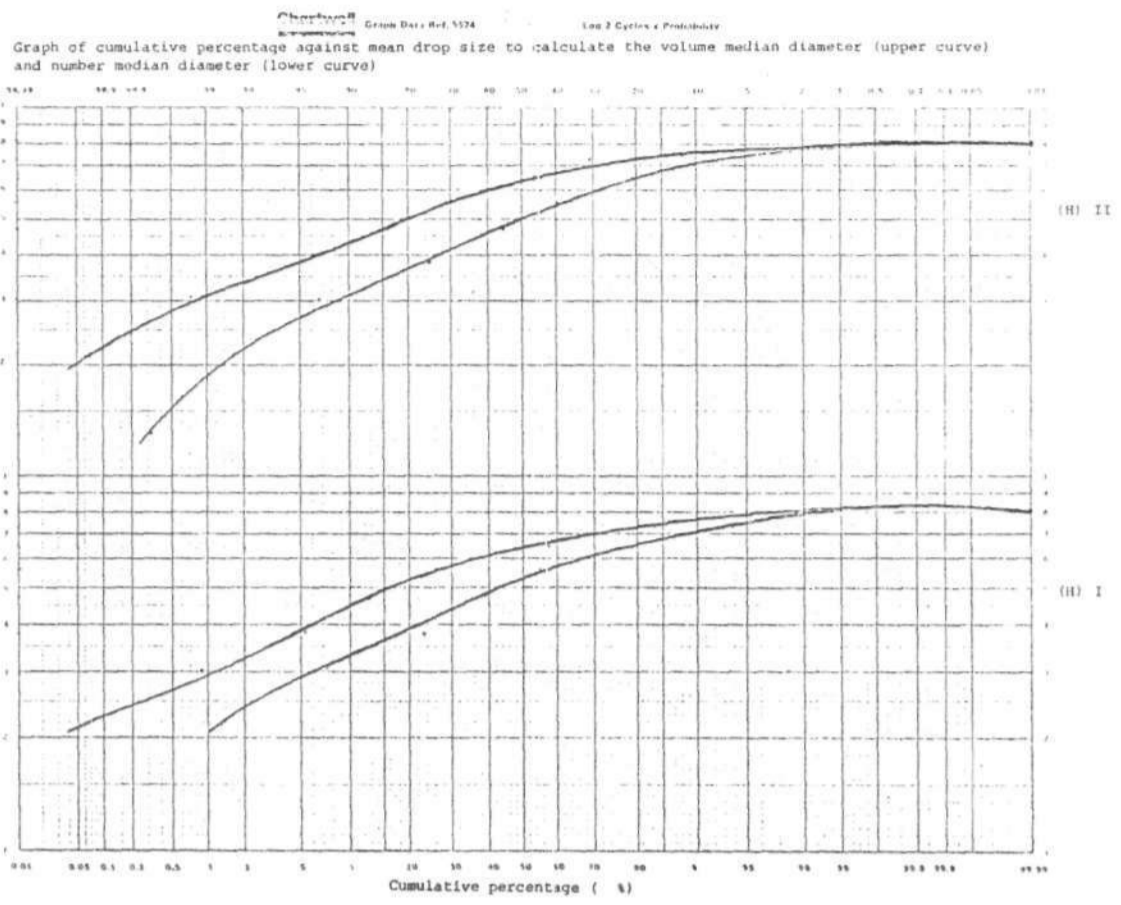
UPPER CLASS SIZE (D)	TRUE SIZE UPPER LIMIT (DT)	MEAN SIZE (DM)	NUMBER IN CLASS (N)	ZN	EZN	DM**3	NDM**3	ZNDM**3	EZNDM**3
10.00	8.60								
20.00	17.20	12.90	0	0.	0.	2146.69	0.	0.	0.
30.00	25.80	21.50	4	1.33	1.33	9938.37	39753.00	0.09	0.09
40.00	34.40	30.10	39	13.00	14.33	27270.90	1063565.00	2.48	2.57
50.00	43.00	38.70	84	28.00	42.33	57960.60	4868690.00	11.34	13.91
60.00	51.60	47.30	52	17.33	59.67	105823.82	5502838.00	12.82	26.73
70.00	60.20	55.90	50	16.67	76.33	174676.88	8733843.00	20.34	47.07
80.00	68.80	64.50	46	15.33	91.67	268336.12	12343461.00	28.75	75.81
90.00	77.40	73.10	21	7.00	98.67	390617.89	8202975.00	19.10	94.92
100.00	86.00	81.70	4	1.33	100.00	545338.51	2181354.00	5.08	100.00
TOTAL: 300						TOTAL 42936479.00			

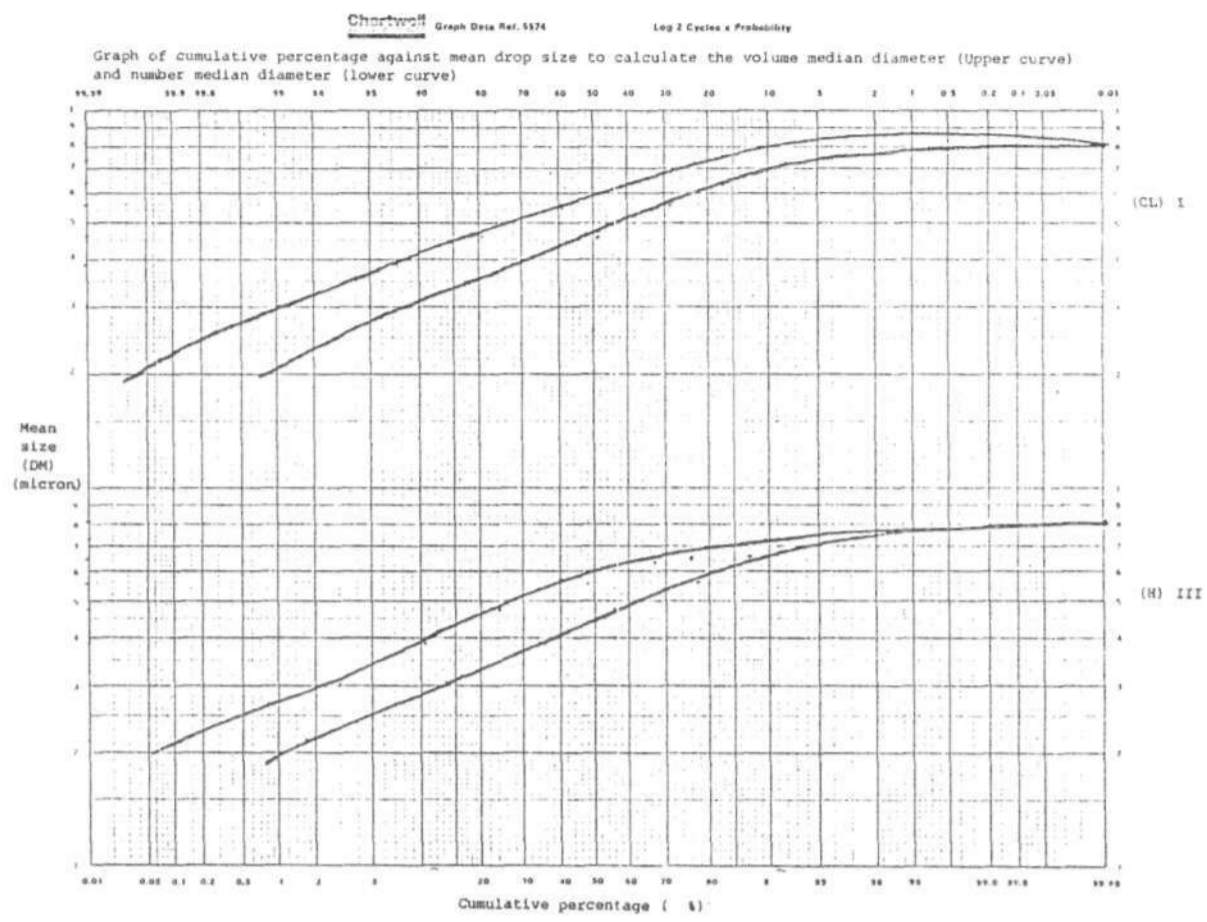
Chartwell Graph Data Ref. 5574 Log 2 Cycles + Probability



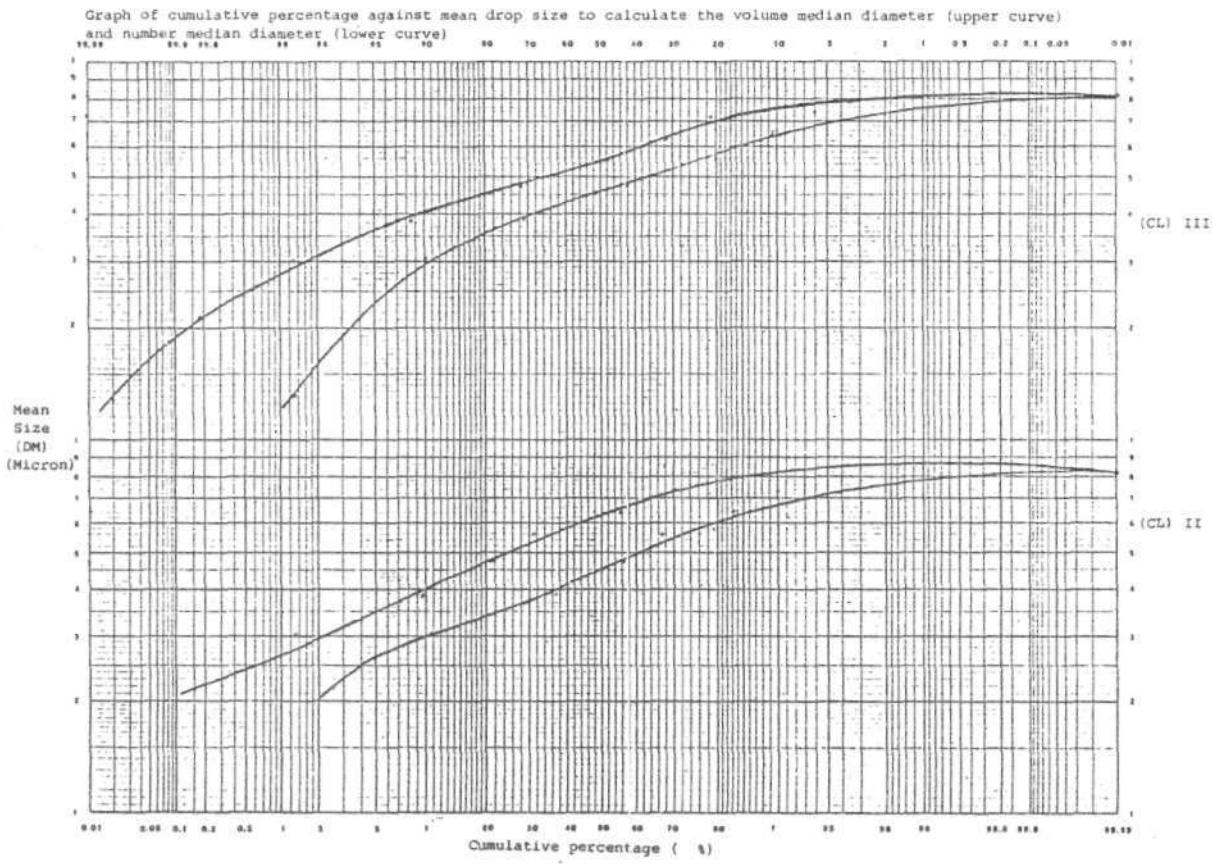




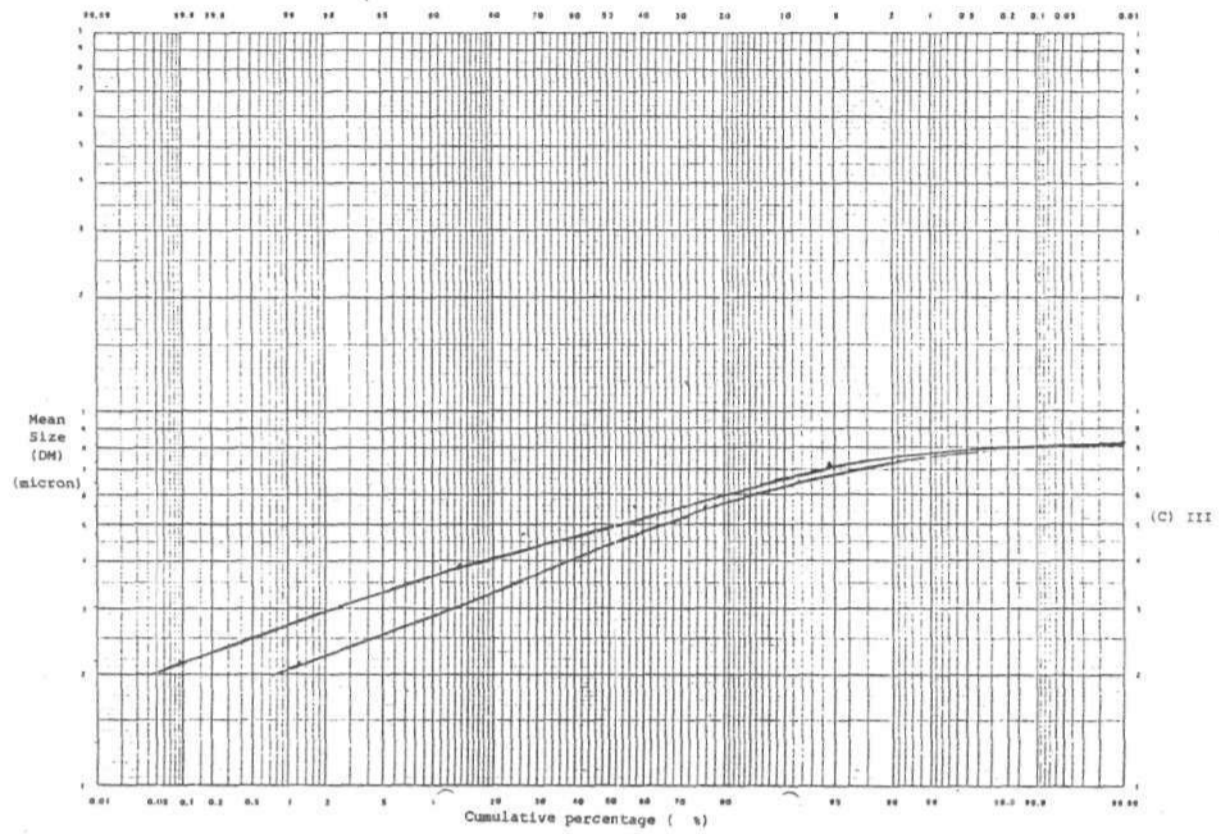




Graph Data Ref. 5574 Log 2 Cycles x Probability



Graph Data Ref. 5574 Log 2 Cycles + Probability



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