STUDIES WITH AIR-ASSISTED ROTARY ATOMISERS FOR PESTICIDE APPLICATION

by

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This thesis is dedicated to my parents, Gillian and Geoffrey, for their love and support throughout my academic education and to the worldwide friends I made during the course of this study.

ABSTRACT

Droplet size spectra produced by air-shear, spinning disc and rotary cage atomisers fitted to motorised knapsack mistblowers were measured. All atomisers produced spray containing droplets of aerosol and fine mist size, but the rotary atomisers allowed greater control over droplet size.

Empirical models were developed to relate liquid physical properties, flow rate, airstream velocity, rotation rate and atomiser design variables to the droplet size spectra parameters Volume Median Diameter (VMD), the ratio of Volume and Number Median Diameters (VMD/NMD ratio), Volume Average Diameter (VAD), and the percentage volume of spray with 40-100 μm diameter droplets considered to be most suitable for <u>Spodoptera exempta</u> control.

A slotted rotary drum atomiser generating its own axial airstream was developed. VMD/NMD ratios were lower or equal when drums rotated in the vane direction than for rotation opposing the vane direction. Peripheral vane teeth reduced the VMD/NMD ratio. The VMD decreased when grooves across the vanes fed liquid to the teeth.

A motorised knapsack mistblower fitted with a rotary cage atomiser was used to distribute spray within canopies infested with Spodoptera exempta larvae. Deposition of droplets of a 2.4% ultra-low volume formulation of cypermethrin at different distances downwind of the spray track at various heights and orientations was assessed. Larval mortality was concurrently assessed at each sampling distance. A minimum of 28 droplets was required per square centimetre to achieve 95 percent larval kill.

Experiments in a tree canopy obtained improved spray coverage on all target surfaces at reduced volume application rates when the hollow cone nozzles on an axial fan sprayer were replaced with spinning disc atomisers. The

spinning disc atomisers also reduced the total volume of liquid lost to the ground beneath trees by 70 percent. These improvements were due to a reduction in the VMD from 465 μm for the hollow cone nozzles to 67 μm for the rotary atomisers.

ABBREVIATIONS

ai	=	active ingredient
BOSS	=	Biological Optimum Spray (droplet) Size
CDA	=	Controlled Droplet Application
CV	=	Coefficient of Variation
D	=	atomiser diameter
d	=	droplet diameter
df	=	degrees of freedom
E	=	collection efficiency
l	=	dimension of target
LMD	=	Length Mean Diameter, D_{10}
LSD	=	Least Significant Difference
m	=	cage mesh size (apertures/inch)
min	=	minute
ml	=	mililitre
n	=	sample size
N	=	wet rotation rate
N_o	=	dry rotation rate
NMD	=	Number Median Diameter, D(n,0.5)
p	=	probability
PSA	=	Particle Size Analyser
psi	=	pounds per square inch
Q	=	flow rate
r	=	linear correlation coefficient
rpm	=	revolutions per minute
SE	=	Standard Error
sec	=	second
SMD	=	Sauter Mean Diameter, D_{32}

SS	=	Sum of Squares
U	=	mean airstream velocity (m/sec)
ULV	=	Ultra Low Volume
um	=	micrometre
v	=	liquid kinematic viscosity (cS)
VAD	=	Volume Average Diameter, D(3,0)
VMD	=	Volume Median Diameter, D(v,0.5)
V_o	=	droplet velocity (m/sec)
VO	=	Volumetric percentage of droplets with diameter 40-100 μm.
v/v	=	volume to volume ratio
w/v	=	weight to volume ratio
z	=	optimum number of teeth on atomiser periphery
	=	liquid surface tension (kg/sec^2)
μ	=	liquid dynamic viscosity (cP)
p	=	liquid density (kg/m^3)
μm	=	micrometre

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Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

Air-assisted spraying is often used for the application of pesticides including fungicides and insecticides. Air is used to atomise liquid into droplets and/or to project the droplets towards the pest or its habitat. Air assistance may also improve the collection efficiency of the target (May and Clifford, 1967).

Air-assisted sprayers are also used with protected crops such as in glasshouses, and for small areas of vegetable crops. Air-assisted boom sprayers have been used to achieve improved spray penetration into field crops (Taylor and Anderson, 1991, Western and Hislop, 1991). The earliest air-assisted spraying was probably the application of fungicides to vines in the 1880's using a bellows to atomise and transport liquid from a gravity drip tube (Large, 1940). Axial, centrifugal and cross-flow fan air-carrier sprayers have become widely used in vehicle-mounted operations since the late 1930's (Rose, 1963), especially for applications to tree crops.

The hydraulic and straight jet air-shear nozzles on many air-assisted sprayers produce relatively large droplets and wide droplet spectra (Hewitt, 1991a; Furness and Pinczewski, 1985). Many workers have observed relatively narrow droplet spectra from spinning discs (Bateman, 1989), rotary cage atomisers (Parkin and Siddiqui, 1990), rotary sleeve atomisers (Howitt et al, 1980) and slotted rotary drum atomisers (Rokicki and Wills, 1987), although there have been few studies on the effects of air-assistance on rotary atomisation.

Aerosols and fine mist sprays have been defined as distributions of droplets with volume median diameter values of less than 50 and 50 to 100 μm respectively (Anon, 1971). They are often used for drift spraying to control insect pests, both from aircraft (Lee et al, 1975) and from the ground (Lee, 1964), whilst mists are often applied to leave a deposit on surfaces which the pest may come into contact with in its habitat.

Controlled droplet application (CDA) has become increasingly recognized as important for the application of minimal volumes of pesticide to achieve effective pest control with minimal environmental contamination and product wastage. CDA sprays have relatively narrow droplet size spectra.

This study evaluated the effects of changes in liquid type and flow rate, atomiser rotation rate, air shear velocity, and atomiser design upon droplet size spectra. To be suitable for a variety of different spraying situations, an atomiser should produce required droplet size spectra over a range of liquid flow rates, have low power consumption, be low cost, lightweight, easy to maintain and service, be durable in different environmental conditions, be compatible with a wide range of formulation types and carrier chemicals, and be protected from damage during operation, transport and storage.

Operator safety is important, so any parts liable to cause injury such as rotary components should be well secured. High voltage generators should be well earthed. Hot exhausts should have guards, ideally of a material which does not itself become dangerously hot - the metal exhaust guards on many motorised knapsack mistblowers can also become very hot whereas heat-resistant plastic remains fairly cool. Formulation tanks and liquid feed tubes should be well sealed and clamped to avoid operator contamination. Consideration has been given to operator safety factors such as these when assessing atomisers in this study.

Laboratory experimentation has been supported by field trials to study droplet deposition and control of larvae of Spodoptera exempta on grass and maize. Spray coverage of grapefruit trees using air-assisted hydraulic and rotary atomisers was also investigated.

1.2. LIQUID ATOMISATION

Atomisation involves the disintegration of bulk liquid into droplets. An input of energy is required to overcome the surface tension force to break up the liquid. The theoretical minimum energy required to produce the i th droplet from the bulk liquid is σA_i (Anon, 1988). Liquid viscosity exerts a stabilising influence by opposing changes in system geometry (Lefebvre, 1989). Most atomisers are inefficient and utilise more than the theoretical minimum energy, especially where energy is also required to transport the atomised droplets to the target.

Atomisers and nozzles are usually classified according to the type of energy used, namely hydraulic, gaseous, centrifugal, kinetic, thermal and electrohydrodynamic (Matthews, 1979). Lefebvre (1989) used a similar classification scheme but also included ultrasonic energy. Primary atomisation of liquid may be followed by secondary disintegration into smaller droplets by the same or a different energy type.

Many workers have described atomisation processes. Rayleigh (1878, 1894) mathematically studied the instability of an inviscid column of liquid (a jet or ligament), considering only inertial and surface tension (capillary) forces. He found that a free liquid column is unstable to axisymmetric disturbances with wavelength greater than the circumference of the ligament. Weber (1931) and Chandrasekhar (1961) noted the effects of viscosity upon the most amplified wavelength. Clark and Dombrowski (1972) used high speed flash and cine-photography to observe the formation of droplets by rim, perforated and wavy sheet disintegration from fan hydraulic nozzles. Parkin (1973) reviewed ligament and liquid jet instability, including the formation of satellite droplets which make droplet spectra bi- or multi-modal.

Lefebvre (1989) differentiated between air-assisted and air-blast atomisation by the air velocity and volume. The former involves relatively small quantities of air flowing at very high velocities (usually sonic), whilst the latter involves large amounts of air flowing at lower velocities (up to 100 m/sec). Hislop (1991) suggested that the use of terms like "air-blast spraying", "mist blowing" and "air-carrier spraying" was often misleading due to poor definition, and could be replaced with the term "air-assisted spraying". The term "air-assisted spraying" is used in this study to describe spraying where an airstream is involved both to atomise and move liquid from a sprayer to a target. To avoid confusion with conflicting terminology, air velocities and volumes are given for all sprayers involved.

1.3. ATOMISER DESIGN

The performance of an atomiser depends upon its design, size and geometry; and on physical properties of the liquid and gaseous phases. The shape, size and position of the liquid release orifice has an important influence upon air-shear atomiser performance.

REGULATION OF LIQUID FILM THICKNESS

Where atomisation occurs by the breakdown of liquid sheets into ligaments and, or droplets, the thickness of the liquid sheet leaving the atomiser is important. A continuous liquid sheet of minimal uniform thickness should be exposed on both sides to the maximum possible relative airstream velocity to achieve efficient atomisation (Lefebvre, 1989).

Thick fluid layers tend to lag on rotary atomisers with a mean tangential velocity less than that of the surface. Although Matsumoto et al (1985) suggested that lag was not normally greater than 20 %, rotary atomiser design should aim to reduce or avoid this 'slippage' of liquid to enable the maximum energy to be imparted to it. Slippage can usually be delayed by the addition of grooves to the surface across which liquid travels. Liquid tends to adhere to such grooves due to surface tension, and will be guided and regulated towards the atomiser periphery. It is important to avoid the accumulation of particles in grooves since these may promote slippage and encourage liquid to leave the surface before reaching the disc or drum periphery.

LIQUID ISSUING SURFACE

The addition of teeth or 'zero' issuing surfaces (Bals, 1969) to the periphery of a rotating surface enables droplet formation in the ligament disintegration mode to occur at relatively higher liquid flow rates. Craig (1990) studied tooth design for a fluid-driven spinning disc, the Waterwheel. It was found that increased tooth sharpness caused cleaner fluid detachment leading to greater ligament stability and the formation of smaller droplets.

Christensen and Steely (1980) found that increasing numbers of teeth were required to maintain ligament formation with increasing disc diameter and rotation rate (Table 1.1).

Table 1.1. Optimum number of teeth required for ligament formation for different diameter discs at different rotation rates.

Disc diameter (mm)	Rotation rate (RPM)	No. teeth per disc	No. teeth per cm^2
50	1000	37.6	2.4
50	3000	94.6	6.0
50	5000	145.4	9.3
100	1000	56.6	1.8
100	3000	142.5	4.5
100	5000	219.0	7.0
200	1000	85.2	1.4
200	3000	214.5	3.4
200	5000	330.0	5.2

Source: Christensen and Steely (1980), cited in Lefebvre (1989).

Christensen and Steely (1980) derived the following equation for calculating the optimum number of teeth:

$$z = 0.215.[(p.w^2.D^3)/\sigma]^{5/12}.[(p.\sigma.D)/\mu^2)]^{1/6}$$

where z = optimum number of teeth

p = liquid density (kg/m^3)

w = disc rotation rate (rad/sec)

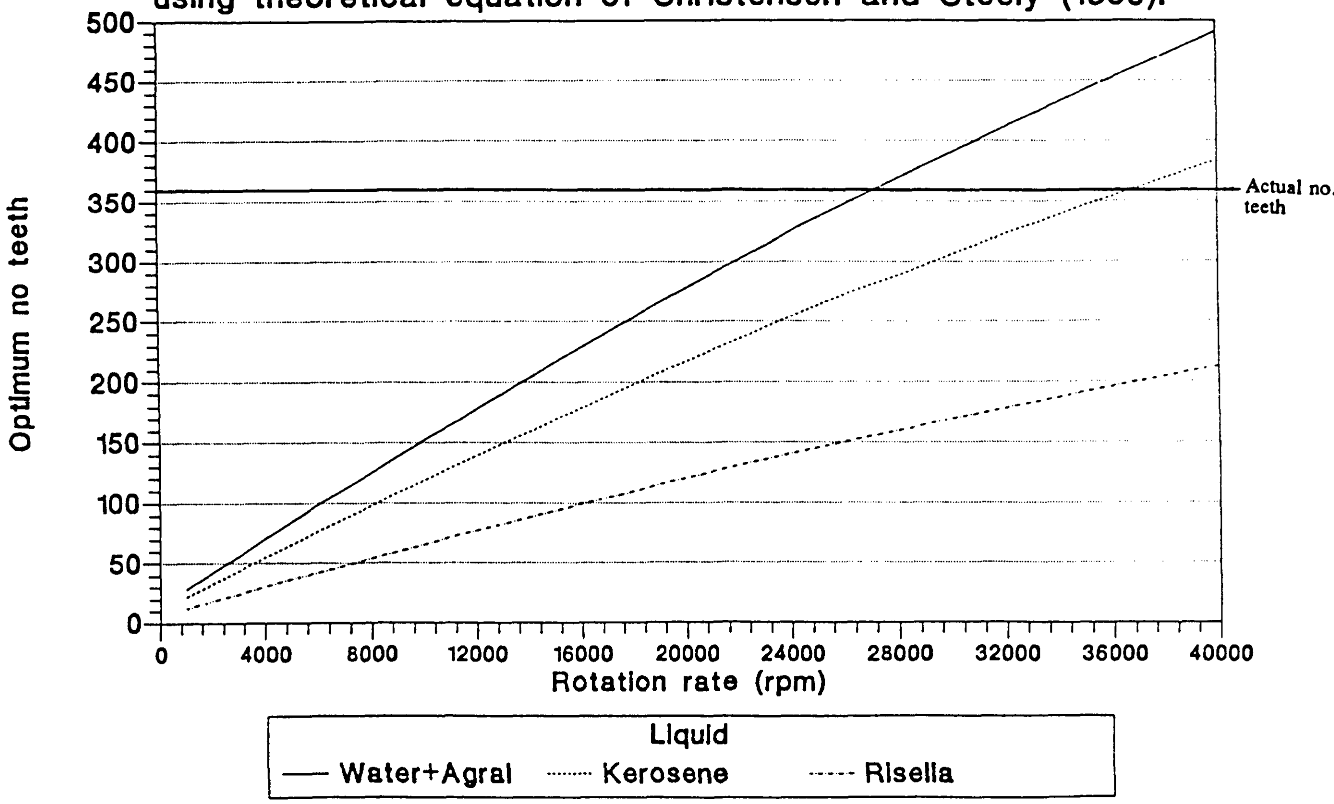
D = disc diameter (m)

σ = liquid surface tension (kg/sec^2)

μ = liquid dynamic viscosity (kg/m.s)

This equation is of limited value because it does not take account of liquid flow rate which affects atomisation. The X1 cupped disc evaluated in this study had a diameter of 52 mm. The optimum number of teeth for spraying the liquids used in this study, water+Agral, kerosene and Risella at different rotation rates has been calculated using the above equation (Fig 1.1). The 360 teeth present on the X1 atomiser are above the theoretical optimum numbers needed to atomise water+Agral at rotation rates up to approximately 27,000 rpm; kerosene at rates up to 37,000 rpm and Risella at rates above 40,000 rpm.

Fig 1.1. Optimum no teeth required for ligament formation from X1 at different rotation rates with different liquids, determined using theoretical equation of Christensen and Steely (1980).



1.4. AIR-SHEAR ATOMISATION

The simplest air-shear nozzle comprises a single open tube through which the liquid is pumped or forced by pressure into the airstream. Many knapsack mistblowers use such a system. The characteristics of the droplet cloud produced will depend upon the diameter of the air and liquid feed tubes and the position of the liquid tube in the airstream. Shaw and Jasuja (1987) conducted tests with water injected into air velocities up to 80m/sec. They observed that the angular orientation of the liquid orifice in the airstream has a noticeable impact upon atomization performance.

Nagaosa et al (1978) used high speed flash photography to observe the development of regular symmetrical disturbances in liquid giving rise to break down into droplets. Breakup length decreased as air shear velocity increased. To achieve efficient atomisation for the production of small droplets, the liquid should be released into the highest air velocity zone (usually where the air outlet tube is narrowest). Aigner and Wittig (1978) found that geometry and air speed had a greater effect upon droplet spectra than the liquid film inlet position and the diameter of the atomisation edge.

Other systems use two or more liquid release points. Atomisation efficiency depends to an extent upon the surface area over which the liquid is spread at the nozzle.

Various nozzle designs have developed with differing surface areas. Some use serrated surfaces with many zero issuing surfaces ("teeth") to increase the surface area at the point of atomisation. Other systems use two or more air tubes for spraying multiple swaths. Many workers have described the breakdown of liquids into droplets. With twin fluid atomisers, the relative liquid-air velocities are important. Weber (1931) showed that the wavelength of disturbances tended to decrease as the relative liquid-gas velocity increased. Castleman (1932), Haenlin (1932) and Ohnesorge (1937) found that at low relative liquid-gas velocity, capillary and viscous forces were predominant. At higher relative velocity, the point of droplet formation moved nearer to the orifice and the fundamental wavelength and droplet size decreased. Although the droplets were smaller, the range of drop sizes was larger.

1.4.1. MOTORISED KNAPSACK MISTBLOWERS

One of the most important portable air-assisted sprayers today is the motorised knapsack mistblower, widely used in tropical countries for the control of tree and field crop pests. Hislop (1991) reported that the first motorised knapsack mist-blower was produced in the Netherlands around 1949.

All motorised knapsack mistblowers available in 1991 had a 35 or 60 to 77 cm^3 two-stroke petrol engine which drove a centrifugal fan producing an airstream usually with a mean velocity between 60 and 120 m/sec at the outlet. The fan may also pressurise the spray tank to force liquid to flow to the nozzle. Liquid delivery is improved on some models by an engine-shaft driven pump.

There are many different machines available with various attachments to allow modification for dust and granule applications. Many of the currently available machines have been evaluated and compared (Lee, 1962; Anon, 1976; Clayphon, 1971; Arnold and Thornhill, 1979; Clayphon, 1979), although detailed investigations have not been made to determine droplet spectra for the different atomiser types, liquid flow rates and air shear velocities. Several workers have studied knapsack motorised mistblowers adapted for ULV spraying (Clayphon, 1974; Thornhill, 1974).

Liquid atomisation is achieved in all the systems when the liquid meets the air from the blower.

1.4.2. VEHICLE-MOUNTED AIR-CARRIER FAN SPRAYERS

Vehicle-mounted air-carrier sprayers use fans to atomise liquid and, or to project the spray towards the target. Many use hydraulic nozzles to atomise large volumes of liquid for orchard spraying. Others use twin fluid or rotary nozzles to produce smaller droplets for relatively lower volume applications.

Cross-flow, centrifugal and axial fans have all been used on different sprayers. Miller and Hobson (1991) reviewed the characteristics of these fan types. The fan needs to generate a sufficient volume of air to displace the air within the canopy being sprayed with air carrying spray droplets, and to move the leaves to encourage droplet deposition on all leaf surfaces (Carmen and Jeppson, 1974). Air velocity should be sufficient to carry droplets towards all target areas within the canopy. Axial and centrifugal fans tend to produce high speed, turbulent airflows. Cross-flow or tangential- flow fans produce relatively laminar airflows. They also tend to be smaller and more power-efficient (Van Ee et al, 1985).

Cross-flow fans have been stacked for spraying tree crops (Van Ee et al, 1985) using rotary cage atomisers with encouraging results. The use of rotary atomisers to replace hydraulic nozzles may become increasingly common for achieving reduced application volumes with smaller droplets and narrower droplet spectra than those available from hydraulic nozzles.

1.5. ROTARY ATOMISATION

Rotary atomisation involves the break-down of liquid leaving a rotating surface under centrifugal force. The rotating surface may be a flat, vaned or cupped disc; or a perforated or slotted cylinder. On a dynamically-balanced, equi-symmetric rounded surface, liquid should be uniformly spread giving rise to similar atomisation at each liquid issuing surface or point. Karim and Kumar (1978) suggested that a uniform liquid film thickness on a rotating cup will be promoted by the following conditions:

a) a large centrifugal force relative to the gravitational force,

b) minimal cup vibration whilst rotating

c) a constant liquid flow rate onto the cup

As with other types of atomisation, the droplet size spectra characteristics depend to a great extent upon the energy input. Air-assisted rotary atomisation utilises air-shear and rotary energy. With windmill blade driven systems, the air velocity directly affects the rotation rate of the atomiser for a given blade angle (Spillman and Sanderson, 1982. It is often difficult to evaluate the relative importance of the air velocity and the atomiser rotation rate. Many previous studies have suggested that rotation rate is of greatest importance in determining droplet size spectra, without studying air velocity independant of rotation rate. In this study these two variables have been isolated for independant investigation.

1.5.1. ATOMISATION FROM CUPPED SPINNING DISCS

When liquid is released onto the surface of a rotating disc, it spreads into a circular film which forms ligamentary streams along the disc edge. Centrifugal atomisation from spinning discs has been studied by several workers and reviewed by Dombrowski and Munday (1968), Matsumoto et al (1985) and Bateman (1989).

Droplet spectra characteristics of cupped spinning disc atomisers are influenced by design features including disc size and shape. Tanasawa et al (1978) found that the critical flow rate did not increase with increase in cup cone angles.

MODES OF ATOMISATION

Many studies of atomisation from cupped spinning discs have not involved air-assistance.

DIRECT DROPLET FORMATION

Hinze and Milborn (1950) described three regimes of liquid flow from smooth-rimmed rotary cups. At very low flow rates, rings of liquid form at the cup edge. The continued flow of liquid into the ring causes an increase in inertia leading to the development of disturbances on the outer ring edge. These disturbances grow until the surface tension of the liquid is overcome, whereupon liquid leaves the ring as discrete direct droplets of very uniform size.

Lefebvre (1989) observed that one of the earliest equations to determine maximum drop diameter, $d_{0.999}$, from flat disc rotary atomisers was determined by Bär (1935):

$$d_{0.999} = (1.07/N).[(\sigma/Dp)^{0.5}]$$

where N = rotation rate (rps)

σ = surface tension (kg/sec^2)

D = disc diameter (m)

p = liquid density (kg/m^3)

A similar equation was given by Walton and Prewett (1949) for calculating the diameter of droplets produced by direct drop formation:

$$d = k.\frac{(1\sqrt{\sigma})/(D.p)}{w}$$

where d = droplet diameter (μm)

w = angular speed (rad/sec)

σ = surface tension (mN/m)

D = disc diameter (mm)

p = liquid density (g/cm^3)

k = constant, approximately 3.76 (Fraser, 1958)

Both these equations indicate that droplet size will tend to increase with decreasing rotation rate, increasing disc diameter, increasing liquid surface tension and decreasing liquid density.

Tanasawa et al (1978) produced a similar equation which also took account of the influence of liquid viscosity upon droplet size. Their equation for Sauter Mean Diameter (SMD) was:

$$SMD = 27/N\ (\sigma/dp)^{0.5}.[1+(0.003Q/dv)]$$

where v = kinematic viscosity (m^2/sec)

LIGAMENT FORMATION

With increasing flow rate, drops begin to merge to form ligaments which subsequently break down into drops due to their capillary instability (Rayleigh, 1878). The droplet spectra produced by this mode of atomisation are usually relatively narrow although wider than those associated with direct droplet formation. Increasing numbers of satellite droplets, formed from threads of liquid as droplets leave ligaments, may cause a decrease in the mean diameter of a spray cloud forming in the transitional phase between direct drop and ligament formation (Dombrowski and Lloyd, 1974).

The complexity of ligament disintegration has made the derivation of equations for the prediction of drop size production difficult. Several equations have been proposed including:

$$d \approx Q^{0.3}/(w^{1}.D^{0.5})$$

(Kamiya and Kayano, 1979), and:

$$d \approx 1.87.(Q^{0.44}.\sigma^{0.15}.\mu^{0.017})/(D^{0.8}.w^{0.75}.p^{0.16})$$

(Frost, 1981)

where Q = flow rate (m^3/sec)
μ = liquid dynamic viscosity (cP)

SHEET FORMATION

At higher flow rates, the ligaments become increasingly numerous until they merge to form a sheet of liquid which breaks down giving rise to a relatively wide range of droplet sizes.

Fraser and Eisenklam (1956) derived the following equation for determining approximate droplet size from sheet disintegration:

$$LMD = (0.76/N).[(\sigma/D.p)^{0.5}]$$

where LMD = Length Mean Diameter, D_{10}

Tanasawa <u>et al</u> (1978) calculated a similar equation taking account of liquid flow rate:

$$SMD = 15.6\ (Q^{0.5}/N).(\sigma/d^2.p)^{0.4}$$

TRANSITION BETWEEN MODES OF ATOMISATION

Transition from one mode to the next is promoted by increased flow rate, atomiser rotation rate, fluid density and viscosity, and decreased disc or drum diameter and fluid surface tension. Tanasawa <u>et el</u> (1978) derived the following equations for calculating the critical transitionary flow rates between modes:

Direct drop formation:

$$q \leq 168\ (D/n)^{2/3}\ (\sigma/p).[1 + 10(\mu/(p.\sigma.D)^{0.5})^{1/3}]^{-1}$$

Ligament formation:

$$q = 4800\ (D/n)^{2/3}\ (\sigma/p).[1+10(\mu/(\sigma.p.D)^{0.5})^{1/3}]^{-1}$$

Sheet formation:

$$q \geq 318 \, (D/n)^{2/3} \, (\sigma/p).(p/\mu)^{1/3} \quad \text{for } (Dp/\mu) < 30 \text{ sec/cm}$$

where q = liquid flow rate (ml/min)

D = disc diameter (cm)

n = rotation rate (rpm)

μ = liquid dynamic viscosity (dyn/cm^2)

p = liquid density (g/cm^3)

σ = surface tension (dyn/cm)

AIR-ASSISTANCE

Atomisation is promoted and smaller drops with a narrower size distribution are obtained by providing an annular air blast which induces disturbances causing the film to break up into ligaments then drops. Byass and Charlton (1968) suggested that the largest surviving droplet of spray emitted into an airstream in this way can be calculated by the following equation:

$$d = \frac{k.\sigma}{0.5.p.V^2}$$

(Prandtl, 1952),

where d = diameter of largest surviving droplet (μm)

k = constant varying with droplet size range

V = airstream velocity (m/sec)

Several workers have reported the use of spinning disc atomisers to replace the standard air-shear nozzles on knapsack mistblowers (Clayphon and Thornhill, 1974; MacFarlane and Matthews, 1978). Afreh-Nuamah and Thornhill (1988) used a similar attachment to the Micronex attachment (Micron Sprayers Ltd, Bromyard, Herefordshire, UK) used in this study, but with a high voltage generator facility to add an electrostatic charge. Jollands (1991) compared deposition of cuprous oxide on coffee plants using a Solo 423 knapsack mistblower with standard air shear nozzles and a Solo "Turbo ULV" spinning disc attachment. There was no significant difference in deposition at 2.1-2.8 kg/ha at 560, 53 and 44 l/ha. The Solo spinning disc attachment has fewer "teeth" or zero issuing surfaces than the Micronex. Liquid is released approximately 15mm from the cup of the Solo attachment, whilst it is released directly onto the cup on the Micronex. An additional feature of the Micronex is that liquid is supplied from a 500ml bottle which is pressurised by the air flowing along the mistblower air outlet hose. Liquid flow rate is therefore more independant of liquid outlet height than in systems which use mistblower formulation tank pressurisation to force liquid to flow to the nozzle.

1.5.2. ROTARY CAGE, SLEEVE AND FOAM ATOMISATION

Rotary cage atomisers such as the Micronair AU3000 are widely used for aerial and ground spraying operations. Each atomiser comprises a dynamically-balanced monel metal wire gauze cage which rotates about a fixed hollow liquid-feed spindle. A diffuser lies between the spindle and the cage. The atomiser is driven by twisted windmill blades which cause rotation in a moving airstream. The atomisers differ according to the cage diameter, the AU8000 being the smallest in the series.

Liquid which flows along the spindle is emitted through the spray deflector and thrown centrifugially through a diffuser tube where some initial break up of the liquid is achieved. Atomisation is completed by the liquid being emitted across the wire gauze where it meets the airstream. The mesh size of the gauze may affect atomisation, since liquid may shatter upon impact with the gauze. van Vliet and Picot (1987) suggested that at 49m/sec. air velocity, atomisation occurs predominantly by a jet-on-wire shatter mechanism. Parkin and Siddiqui (1990) derived models for predicting volumetric droplet spectra for the AU3000 Micronair rotary cage atomiser. In this study the smaller AU8000 was evaluated for knapsack or vehicle-mounted equipment.

The AU8000 is available as a conversion kit for axial fan sprayers (Sander, 1991). Field trials showed superior coverage of all leaf surfaces on pear trees sprayed with an axial fan sprayer using AU8000 atomisers at 100 l/ha. than with a similar sprayer using hydraulic nozzles at 200 l/ha.

Hill (1959) described the first rotary cage atomisers used for pesticide application. Whittam (1965) described the "Mini-Spin", a variable pitch, windmill-blade driven rotary cage atomiser very similar to Micronair atomisers but considerably smaller, with a cage diameter of 50mm. Advantages of this atomiser included its relatively low weight, low cost and the more even swath obtainable by using many units on a boom. However, it had a considerably lower flow rate range handling capability than the larger Micronair atomisers.

"Beecomist" atomisers originally had porous sintered steel rotary cylinders. Maximum droplet size was regulated by rotation rate and sleeve pore size (Howitt et al, 1980). Problems occurred if the pores became blocked by particles larger than the pore size. Some Beecomist atomisers use wire mesh cages. Plastic alternatives have been studied (Kinnersley, personal communication). Parkin (1983) observed good droplet size spectra control for rotating metal foam atomisers, however these tend to be relatively expensive to manufacture.

1.5.3. SLOTTED ROTARY DRUM ATOMISATION

Spinning discs are generally only suitable for low flow rate applications due to the limited disc peripheral surface area. Rotary cage, sleeve and slotted drum atomisers have greater surface areas, enabling higher liquid flow rates to be accommodated before atomisation becomes less efficient. Liquid slippage on the surface of rotary drums is generally also reduced allowing the actual speed of drop ejection to be the same as the drum peripheral speed (Fraser and Eisenklam, 1956). Few comprehensive studies have been carried out to derive formulas relating droplet size from slotted drums to variables such as rotation rate, flow rate, drum diameter, relative air velocity and liquid fluid properties. Equations given by Fraser et al (1957) and Friedman et al (1952) relate mainly to spray drying applications, so include variables such as the pressure exponent of evaporation rate and the heat transfer coefficient. These are not relevant to this study. These models were discussed by Lefebvre (1989) and Masters (1976).

Slotted drum atomisers have advantages in being relatively simple and low cost in comparison to most rotary cage, sleeve and foam atomisers. They are mostly used for spray drying, and at present are of limited use in agriculture. The Australian company Auspray Ltd use slotted rotary drum atomisers on various vehicle-mounted agricultural spraying machines. Air-assisted slotted rotary drums are also used on a 'Span Spray' vehicle-mounted boom (Matthews, 1979).

In slotted rotary drum atomisers, liquid released onto the inside of a rotating hollow cylinder passes through a series of longitudinal slots and is atomised at the periphery.

A plastic drum was evaluated in Australia (Rokicki and Wills, 1987). The 30 m/sec centrifugal air flow generated by the drum rotating at 7,000 rpm gave a narrower droplet spectrum than if there was no air flow.

It is often difficult to ensure uniform liquid distribution on the internal surface of rotary drums (Parkin, 1983). A similar problem led to the development of diffusers in Micronair rotary cage atomisers. The use of multiple liquid release or injection points might also overcome or reduce this problem.

Metal slotted drums have been developed in Hungary (Pettenkoffer, 1983). The NORIC (NORIC s/a, Kasteelweg 30, B-3700 Tongeren-Widooie, Belgium) slotted rotary drum atomisers developed in this study are currently used in vehicle-drawn tunnel sprayers. Tunnel sprayers are moving canopies which fully or partly enclose a crop whilst it is being sprayed. An early tunnel sprayer developed at the Institute of Arable Crops Research, Long Ashton, Bristol (Cook et al, 1976) used non air-assisted hydraulic nozzles to spray the enclosed trees. An unmanned air-assisted tunnel sprayer has been developed in the Netherlands (van de Werken, 1991). This machine and the 'Joco' tunnel sprayer (John and Co, Achern, West Germany) described by de Schaetzen (1991) collect, filter and re-circulate liquid which misses or runs off the enclosed tree canopy. Spray loss to non-target environments by drift and runoff should be greatly reduced by these tunnel sprayers.

1.6. CONTROLLED DROPLET APPLICATION

Fraser (1958) was one of the first workers to recognize the value of producing narrow droplet spectra for improving pesticide placement. With the increasing use of ultra-low volume (ULV) techniques since the second world war for locust control (Sayer, 1959), the importance of droplet size increased (Morton, 1975). ULV is of particular advantage where water is of limited availability. Maas (1971) defined ULV as less than 5 l/ha., whilst Matthews (1979) and Fryer et al (1977) suggested different volume application rates for tree and field crops. They suggested ULV be less than 5 l/ha. for field crops and up to 50 l/ha. for tree crops.

The concept of CDA is often associated with ULV spraying, although it can also be important for higher volume rates. CDA is based on the principle that certain droplet sizes are more likely to collect on target surfaces (Bals, 1975).

Different droplet sizes are desirable for different chemicals, meteorological conditions, targets and pests. Where drift is undesirable, larger droplets are preferred, however droplets larger than approximately 300 μm diameter have low deposition efficiency on plants due to their tendency to roll, bounce or shatter upon impact with vegetation surfaces. Mist sized droplets are often applied to foliage (Matthews, 1979).

The use of CDA has several advantages if volume rates can be reduced. Reductions or the elimination of water volume requirements may be invaluable in areas where water is scarce or expensive. Turner (1985) described this as a major advantage of CDA for plantation spraying in parts of Indonesia and Papua New Guinea. Reductions in volumes also can enable savings in time and effort required for spraying operations, and savings in operational costs including energy consumption. Weight reductions may permit easier access of vehicles to wet fields, and less fatigue for hand-operated sprayers.

Possible disadvantages of CDA systems compared to hydraulic systems include increased complexity; decontamination problems due to increased chemical concentration; limitations on choice of pesticide; lower control over spray swath; and hollow-cone spray distributions from spinning discs.

1.7. DROPLET DEPOSITION ON TARGETS

Droplets deposit on target surfaces by sedimentation and impaction (Matthews, 1979). The rates and efficiency of collection are affected by the relative sizes and velocities of the target and droplet (May and Clifford, 1967; Johnstone et al, 1977). Droplet impaction efficiency generally increases with increasing droplet size and relative velocity and decreasing target size (Matthews, 1979). May and Clifford (1967) derived the following functional equation for target collection efficiency:

$$E = f[(p.V_o.\hat{I}.d^2)/(18V.l)$$

where E = collection efficiency

p = droplet density (kg/m^3)

V_o = droplet velocity (m/sec)

d = droplet diameter (m)

V = airstream velocity (m/sec)

l = dimension of target (m)

Uk (1977) considered the increase in collection efficiency generated by increased relative target velocity. A moving target will tend to have an increased collection efficiency providing its orientation relative to the airstream is not altered. Thus a moving leaf may collect more droplets unless it is deflected to become parallel with the airstream (Matthews, 1979).

Natural vegetation targets are often relatively difficult to use for sampling droplet deposition in the field since target orientation is difficult to control and droplets often spread upon the surface, rendering them difficult to observe. Artificial targets are preferred by many workers, for example Kromekote paper (Higgins, 1967), photographic paper (Johnstone, 1960) and silicone-coated slides (Carlisle and Rathburn, 1970). Artificial targets should mimic the natural target as far as possible. Consideration should be given to the texture, size, shape and mobility of the target since these affect collection efficiency for a given chemical (Matthews, 1979). If the spray is tagged with a coloured dye, droplet stains can be identified and counted on target surfaces. Droplets impacting on target surfaces tend to spread, making it difficult to accurately determine their original size, and merge, making them difficult to count.

The variation in spread factors between different liquid types, sample surfaces and droplet size ranges causes the use of paper targets to be of limited accuracy. Magnesium oxide coated slides represent a more reliable sampling surface. These are discussed in detail in section 2.6.

1.8. PESTICIDE DROPLET SIZE AND EFFICACY AGAINST LARVAE

Several workers have studied the relationship between pesticide droplet size and pest mortality. Many workers have recognized the need for laboratory and field trials to determine biological optimum spray droplet size (BOSS)

(Himel and Uk, 1975) for specific targets (Bals, 1973; Graham-Bryce, 1977, Matthews, 1977). Himel and Uk (1975) suggested that the value of BOSS is within the range 15 to 80 μm for most crop pests. Based on a review of work with adult mosquito control, Mount (1970) considered a droplet size range of 5 to 10 μm VMD to be optimal for ground application and 10 to 25 μm VMD optimum for aerial application. Munthali (1984) and Reay and Ford (1977) respectively found there was an inverse relationship between droplet diameter and spray efficiency against Tetranychus urticae (Koch) and Spodoptera littoralis (Boisd.) larvae.

It is usually not necessary, and often wasteful of product, for single droplets to contain many lethal doses. Wasted product may cause undesirable environmental contamination and may increase the development of resistance to the pesticide.

Droplets tend to spread upon impaction on target surfaces, thereby exerting an effect over a larger area than that of the original stain. They have a range of action-at-a-distance which is rarely less than 1 mm (Courshee, 1985).

1.9. SUMMARY OF OBJECTIVES.

In view of the need to produce specific droplet sizes for the control of migrant pests such as Spodoptera exempta, the aims of this study of equipment were:

1. To evaluate and compare the effects of atomiser design, rotation rate, airstream velocity, liquid type and flow rate upon droplet size spectra produced by straight jet air-shear nozzles, the Micron X1 cupped spinning disc, the Micronair AU8000 rotary cage atomiser and NORIC slotted rotary drum atomisers.

2. To evaluate the suitability of a knapsack mistblower-mounted AU8000 atomiser for the application of pesticide to control Spodoptera exempta larvae on grass and maize.

3. To compare droplet deposition within tree canopies sprayed with an axial fan orchard sprayer fitted with X1 rotary atomisers and hollow cone ceramic hydraulic nozzles.

Chapter 2

MATERIALS AND METHODS

2.1. DRIVE MECHANISMS AND AIR SOURCES

Rotary atomisers are usually driven by electric or hydraulic motors or by a moving airstream. A fluid-driven wheel was developed by Kinnersley (1987) and Craig (1990). The drive mechanisms used for this study were direct drives and belt-drives using a variable voltage electric motor, and airstreams from motorised knapsack mistblowers and an axial fan sprayer.

MOTORISED KNAPSACK MISTBLOWERS

Many motorised knapsack mistblowers are commercially available for pesticide applications. All currently available machines have 1.5 to 3.7 kW two-stroke engines with displacements of 35 to 77 cm^3. Two popular machines were used for this study, the Fontan R11-SE (Motan Ltd., W. Germany) and the Guarany CIFA 5 (Industria E Comercio Guarany s/a, Sao Paulo, Brazil) to provide airstream velocities of 87 and 116 m/sec (Table 2.1).

Air volume displacement was measured at the nozzles using a shunt gap meter (Airflow Development Ltd, Lancaster Rd, High Wycombe, Bucks, UK) on a 10 cm diameter tube as

High Wycombe, Bucks, UK) on a 10 cm diameter tube as described by Thornhill (1982). Air velocity at the outlet without any attachments or nozzles was measured using an air pressure gauge (Table 2.1).

Table 2.1. Airstream sources for driving atomisers.

Airstream Source	Air velocity (m/sec)	Air volume (cm3/min)
Fontan R11-SE mistblower	87	6.5
Solo 423 mistblower	100	8.5
Guarany CIFA 5 mistblower	116	10.5

ELECTRIC MOTOR

A 12-24 V d.c. electric motor was used to rotate atomisers in the absence of an airstream, both by direct drive for the slotted rotary drums and by a pulley belt system for the AU8000. Rotation rate was varied by regulating the electric voltage supplied to the motor.

The ranges of rotation rates used for experiments varied between atomisers (Table 2.2) due to differences in atomiser weight and power consumption.

Table 2.2. Experimental rotation rate ranges for atomisers.

Atomiser type	Rotation rate range (rpm)
X1	3000-19000
AU8000	2500-13000
Slotted rotary drums	2500-8000

AIR-CARRIER FAN SPRAYER

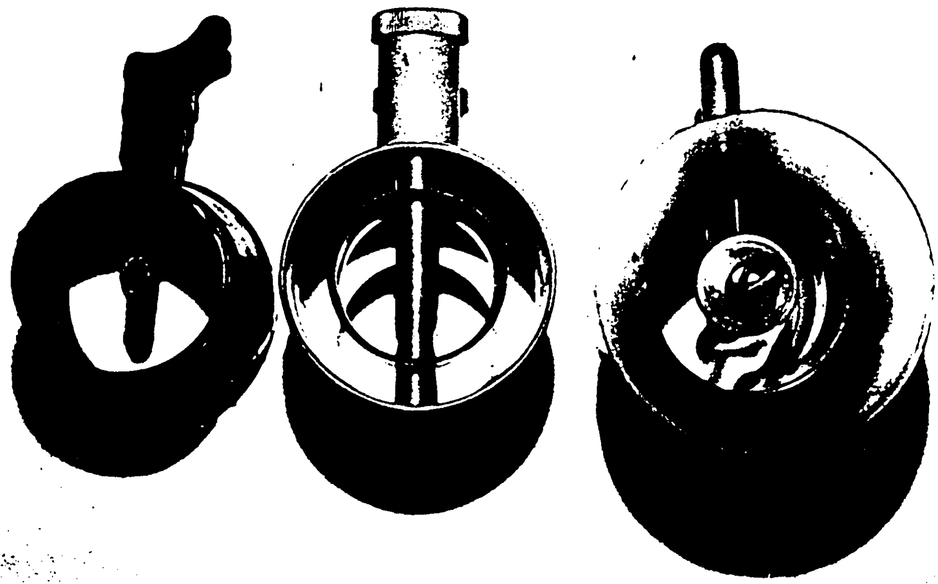
An axial fan orchard sprayer, the FMC 1087 (FMC, 5601 East Highland Drive, Jonesboro, Arkansas, USA) was used to drive X1 atomisers for field trials investigating spray coverage of grapefruit trees. Air velocity at the air outlet duct varied from 49 to 95 m/sec, giving rotation rates of 12,000 to 17,000 rpm.

2.2. ATOMISERS AND NOZZLES

AIR SHEAR NOZZLES

Many different designs of air-shear nozzle are commercially available for use with motorised knapsack mistblowers. Airstream outlet tubes vary in size and shape. Liquid release points vary in number, size, shape, orientation and relative position in the airstream. A comprehensive evaluation of the relative importance of each of these parameters is beyond the scope of this study. Single, twin and multiple liquid release point nozzles (Plate 2.1) were compared in this study.

<u>Plate 2.1. Straight jet air-shear knapsack mistblower nozzles.</u>



Liquid was released into the centre of the airstream in all the nozzles. Liquid direction relative to the airstream and the liquid issuing surface area varied between the nozzles (Table 2.3).

Table 2.3. Characteristics of air-shear nozzles.

Nozzle	NIP	LRD	SAP	SAL	NOD
Solo 423	1	Parallel	19	22	50
Fontan R12	2	Tangential	46	64	42
Semco ULV	6	Tangential	11	108	51

NIP = Number of liquid issuing points

LRD = Liquid release direction relative to airstream

SAP = Approximate total transectional area of liquid injection points (mm)

SAL = Approximate total surface area of liquid issuing surfaces (mm^2)

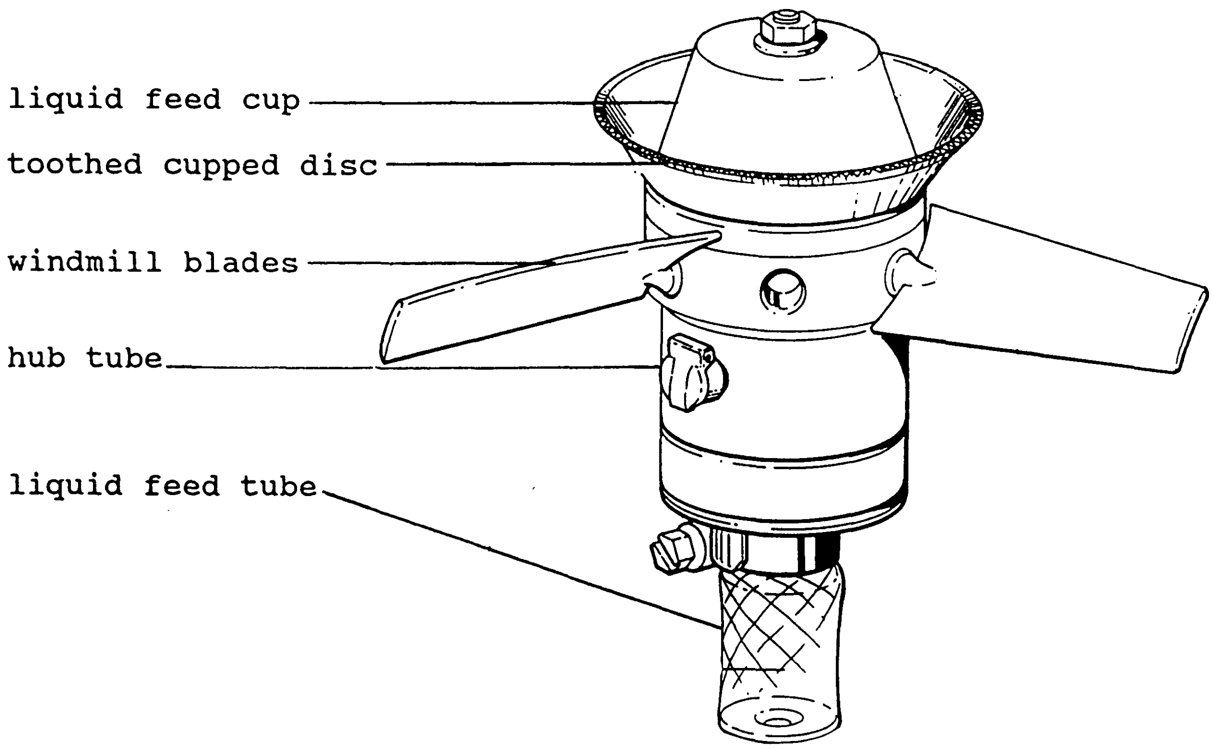
NOD = Nozzle outlet diameter at liquid release point (mm)

The single liquid injector tube nozzle, representing perhaps the simplest type of air-shear nozzle, was from a Solo 423 mistblower. The twin-release nozzle was obtained from a Fontan R12 mistblower and the multiple liquid release nozzle came from a Semco ULV mistblower.

MICRON X1 CUPPED SPINNING DISC

The windmill-blade driven Micron X1 cupped spinning disc atomiser (Fig 2.1) was tested with motorised knapsack mistblowers (the 'Micronex') and with an axial fan orchard sprayer. The X1 discs had a diameter of 52mm with 360 peripheral zero issuing surfaces ('teeth'). The Micronex was driven by variable pitch blades, whilst the orchard sprayer atomiser had fixed pitch blades. Liquid released into the centre of the cups was forced by centrifugal force along the grooves to the outer teeth.

Fig. 2.1. X1 Spinning Disc Atomiser.



Courtesy of Micron Sprayers Ltd.

Rotation rate varied according to airstream velocity and windmill blade angle relative to the airstream (Table 2.4).

Table 2.4. Rate of rotation of unloaded X1 atomiser in different airstream velocities at different windmill blade settings.

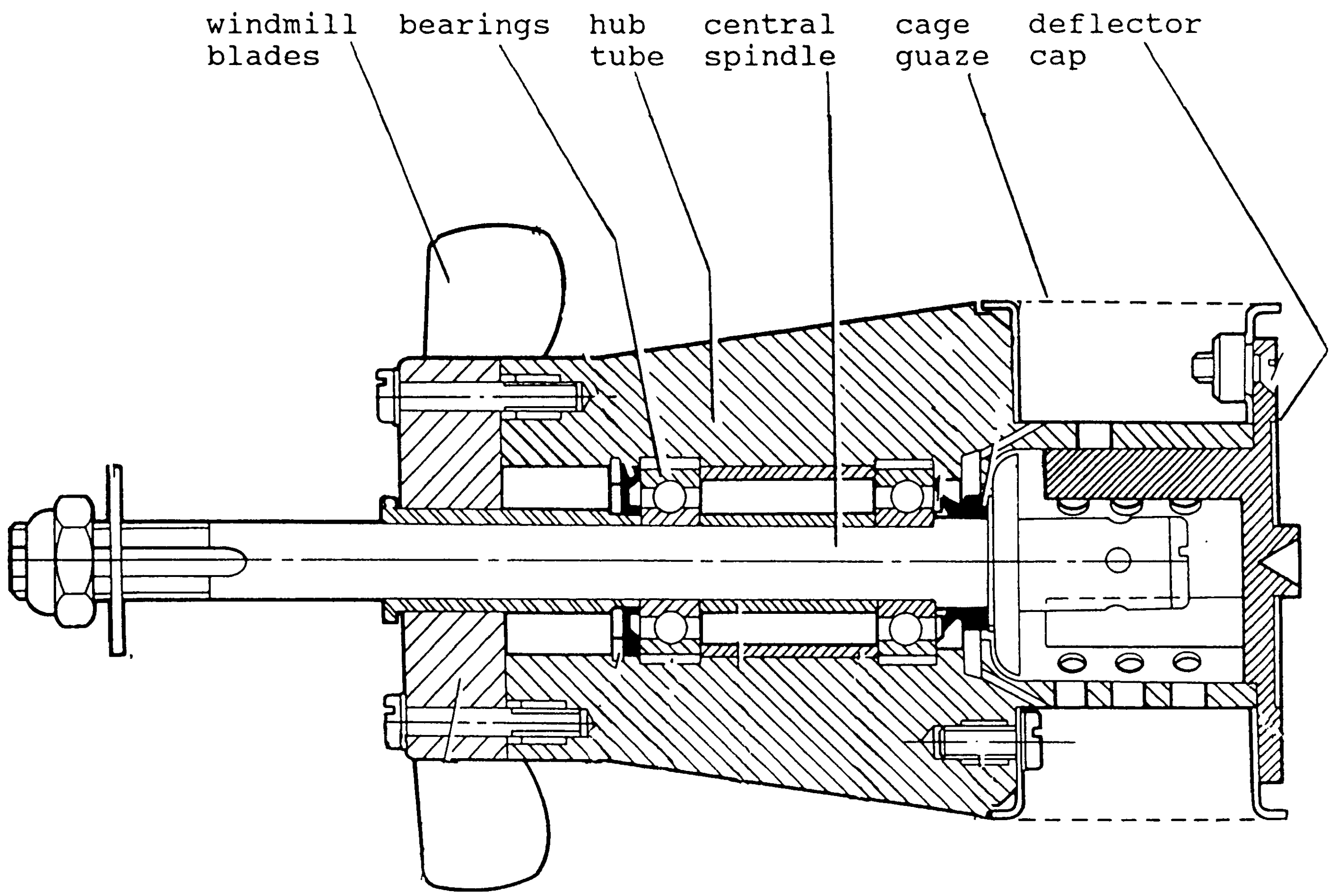
Blade	Airstream velocity (m/sec)	
no	116	87
4	6000	3000
3	9000	6000
2	15000	11000
1	19000	15000

Rotation rates are given in rpm.

MICRONAIR AU8000 ROTARY CAGE ATOMISER

The AU8000 atomiser (Fig 2.2) was described in section 1.5.2. The cage had a length of 40mm and a diameter of 68mm.

Fig. 2.2. AU8000 Rotary Cage Atomiser.



Courtesy of Micronair Ltd.

The rate of rotation of the AU8000 in the motorised mistblower airstreams was varied by adjusting the windmill blade angle (Table 2.5).

Table 2.5. Rate of rotation of unloaded AU8000 atomiser at different windmill blade settings.

Blade setting	Rotation rate (rpm) in 116 m/sec airstream	Rotation rate (rpm) in 87 m/sec airstream
8	100	15
7	810	100
6	1490	880
5	2500	1640
4	4000	2150
3	6000	3400
2	7800	4550
1	11100	6000
0.5	13000	7000

Micronair rotary cage atomisers commercially available in 1990 used size 20 mesh gauzes. In this study, droplet spectra produced by square mesh sizes 20, 30, 40, 60 and a size 10 diamond-grid mesh were compared (Plate 2.2). Tests were also carried out with an AU8000 fitted with and without three different diffuser designs (Fig 2.3).

Plate 2.2. Cage meshes attached to AU8000 atomiser.

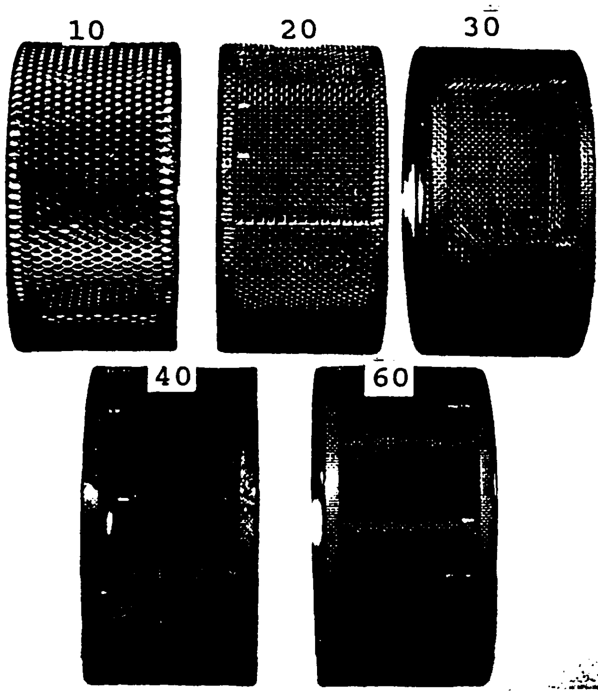
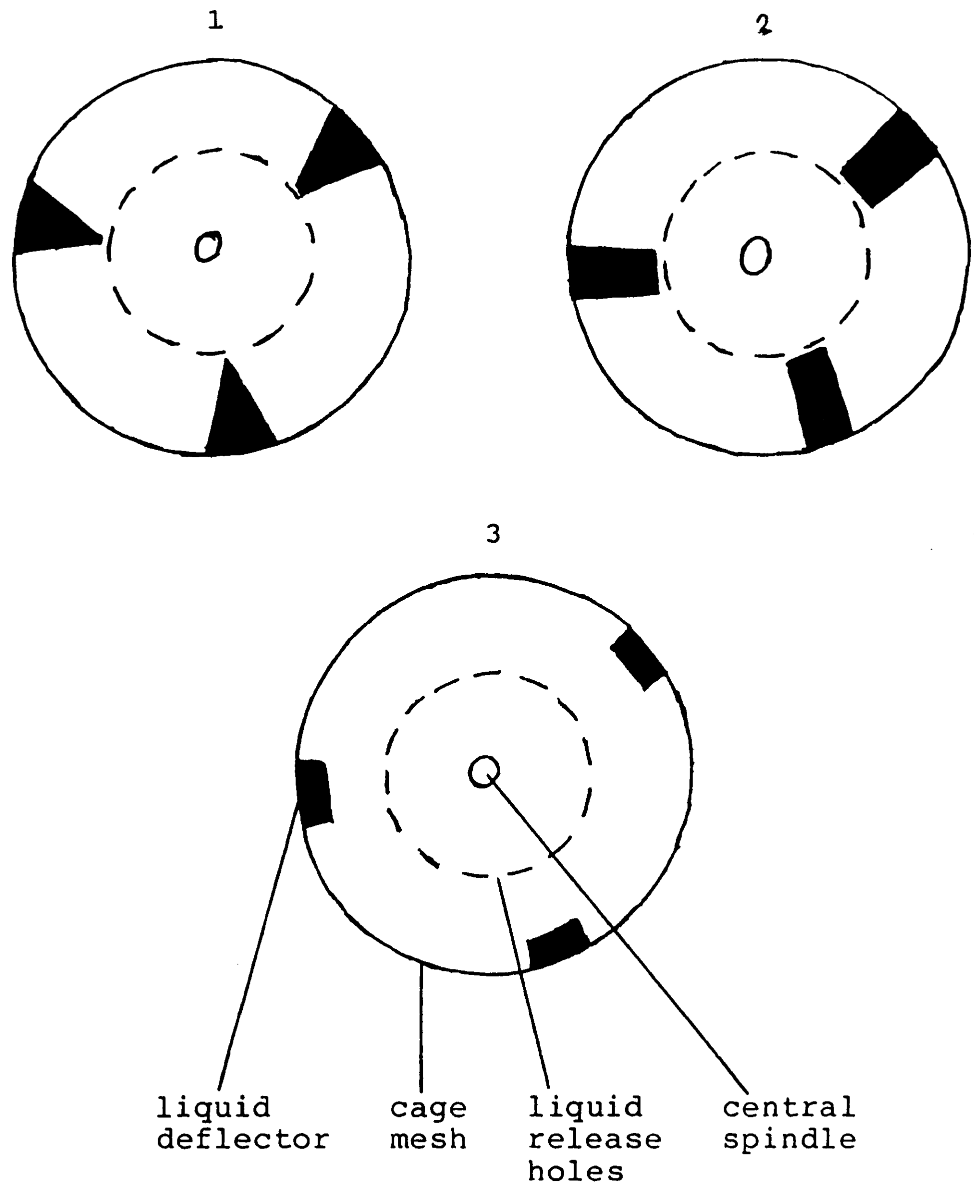


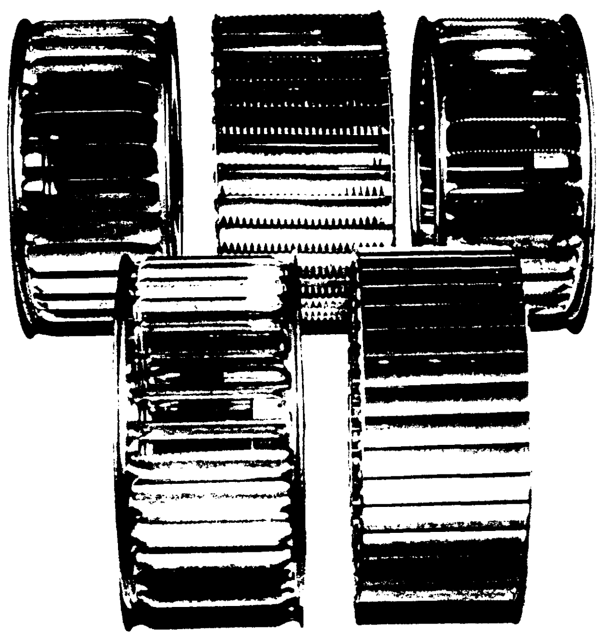
Fig. 2.3. Cross section through different diffusers used with AU8000 atomiser.



SLOTTED ROTARY DRUM ATOMISERS

The slotted rotary drum atomisers were supplied by Noric Spraying Systems, Kasteelweg 30, Tongeren-Widooie, Belgium (Plate 2.3 and Fig 2.4).

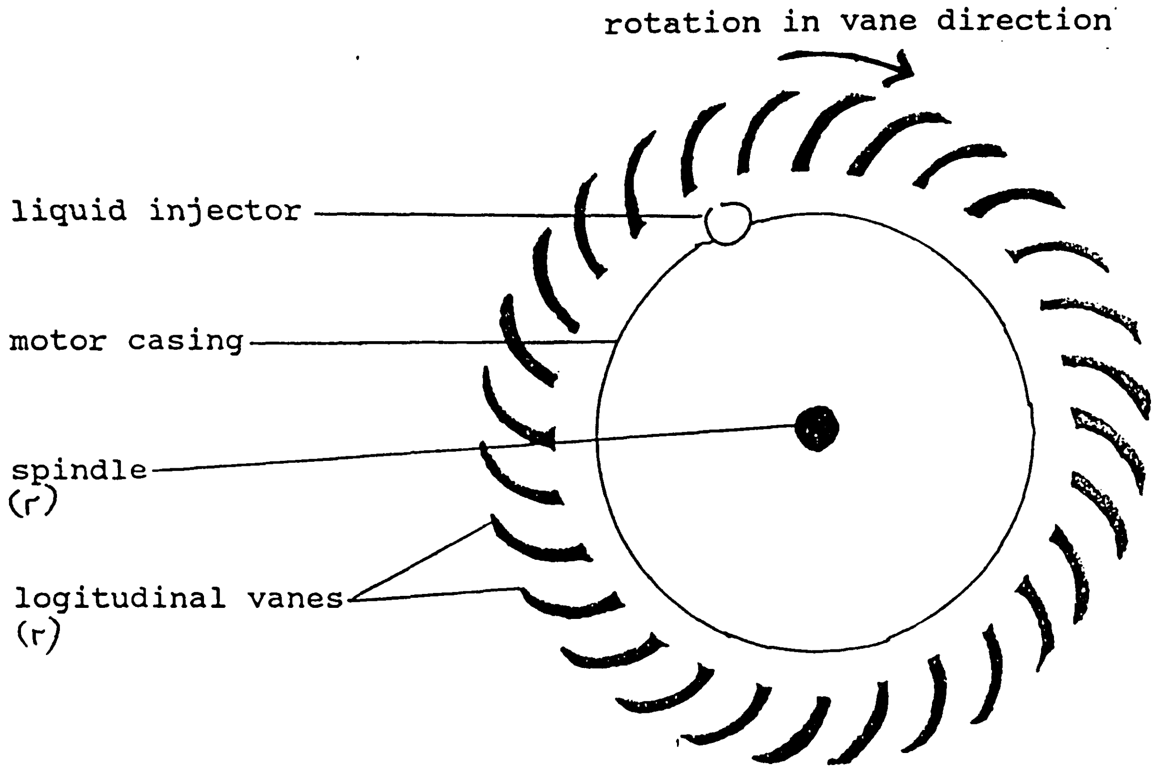
Plate 2.3. Slotted rotary drum cylinders 1 to 5 (upper left to lower right).



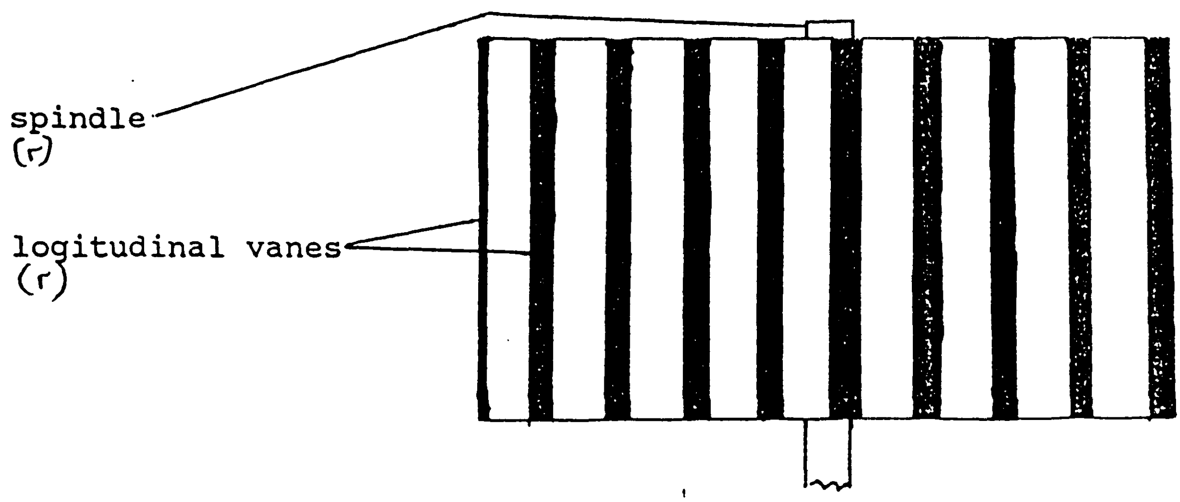
Metal (M) and plastic (P) drums were studied, with different numbers of teeth, vane angles and orientations (Table 2.6). The vanes on the Noric drums were curved, whereas the vanes on slotted drums evaluated in most previous studies have been straight.

Fig. 2.4. Noric Slotted Rotary Drum Atomiser.

a) Cross-section



b) Axial view



r=rotating part

Table 2.6. Description of slotted drum atomisers.

Drum Ref	Drum diameter	Drum length	No. slots	Vane length	Vane width	Vane angle	No. teeth per vane
1M	95	45	29	9	0.5	74 A	60*
2M	95	45	29	9	0.5	45 A	30
3M	95	45	29	9	0.5	74 A	30
4M	95	45	29	9	0.5	74 A	0
5M	95	45	29	9	0.5	45 A	0
6P	102	45	29	13	1.5	45 C	30
7P	88	50	29	13	1.5	45 C	0
8P	88	50	29	13	1.5	45 A	0
9P	88	50	29	13	1.5	45 A	60
10P	88	50	29	13	1.5	45 A	60**

All measurements are in mm.

M = Metal P = Plastic

A = Anticlockwise orientation C = Clockwise orientation

* The teeth on drum 1 were on the outer vane surface only. Teeth on other drums were on both outer and inner vane surfaces.

** Drum 10 was the only drum to have grooves on the inner vane surface to channel liquid and prevent slippage between the inner vane rim and the outer teeth.

Electric power requirements (volts and amperes) to maintain loaded rotation rates of 4000, 5000 and 6000 rpm at increasing liquid flow rates were measured using voltage and current meters.

The design of a fluid injection and distribution system which will deliver liquid as equally as possible to all liquid issuing surfaces is an important aspect of atomiser design. It is often difficult to ensure uniform liquid distribution on the internal surface of rotary drums (Parkin, 1983).

In this study, the use of two liquid feed tubes was compared with a single liquid tube design. All tubes had two longitudinal slits through which liquid was forced under pressure to the interior vane surface. In the absence of liquid flow, both slits were closed. As liquid flow rate increased, the increased liquid pressure caused the slits to open in succession thereby increasing the effective discharge area. A similar effect is achieved with the more complex augmenter nozzles used in some jet engine afterburner systems (Lefebvre, 1989).

After being released on the inner vane surfaces of the NORIC drums, liquid did not instantaneously leave the radial vanes but was forced to the rim at a speed proportional to the centrifugal force created by the rotation of the drum. Each vane received an input of liquid with each complete rotation of the drum. Waves of liquid were established with liquid flowing across the vane surfaces and leaving at the periphery.

An absorbent shroud was placed around drum 7, with a window to allow spray from the vanes closest to the laser beam of a Malvern particle size analyser (section 2.6) to pass across the laser and be measured. A single fluid injector with two slits was used to deliver water+Agral at flow rates of 250, 500, 1000 and 1800 ml/min. The drum was rotated in the clockwise direction at rotation rates of 5000, 6000 and 7000 rpm. Droplet size spectra measurements were taken at each flow and rotation rate with the injector positioned at 0, 90, 180 and 270 degrees to the window. This procedure allowed selective sampling of the spray cloud produced by the atomiser to assess differences in droplet size spectra produced with different injector positions.

The NORIC slotted rotary drum atomiser induces air flow as it acts as an axial fan drawing air by suction into the open end of the drum and out through the vanes. This airstream will interact with the liquid film on the vane surfaces, causing air-shear atomisation in addition to the rotary atomisation induced by the rotation of the drum. In tunnel sprayers and for glasshouse and aerial applications, an addition exterior airflow will be supplied. To simulate this effect, an axial fan was placed behind drum 7 and parallel with the Malvern laser beam. Water was delivered through a single injector situated by the drum vanes nearest the exterior fan.

Airstream velocities measured using an air pressure gauge were 15 m/sec at the drum outlet and 42 m/sec at the exterior fan outlet.

HOLLOW CONE CERAMIC NOZZLES

Hollow cone ceramic nozzles with swirl plates and various different orifice sizes were used with the FMC 1087 axial fan sprayer described in section 2.1. Liquid was pumped through these nozzles at a pressure of 8.8 kg/cm^2.

2.3. TEST LIQUIDS

There are many different commercially-available pesticide formulations with wide ranging physico-chemical properties. A comprehensive evaluation of these was beyond the scope of this study. Liquid density, viscosity and surface tension were considered important in this study because they affect liquid flow and atomisation properties.

Density affects liquid flow rates but has a relatively small effect upon droplet size spectra (Lefebvre, 1989).

Liquid viscosity affects droplet size distributions and flow rates. An increase in viscosity decreases the Reynolds liquid jet or sheet. This delays atomisation and leads to an increase in mean droplet size Lefebvre, 1989).

Surface tension is important since it resists atomisation. The minimum energy required for atomisation is directly proportional to the surface tension multiplied by the increase in liquid surface area.

Water with 0.1 % v/v Agral (ICI, Fernurst, Haslemere, Surrey, UK) surfactant, Kerosene and Risella oils (Shell Chemicals Ltd, Northumberland Avenue, London, UK) were used in this study because they represent the more common extremes of physico-chemical properties encountered in pesticide formulations (Table 2.7).

Table 2.7. Liquid physical properties.

Liquid	Density at 20°C (kg/l)	Viscosity at 20°C (cP)	Surface tension (N/m)
Water+0.1 % Agral	1.000	1.05	0.040
Kerosene	0.783	1.78	0.026
Risella	0.875	32.40	0.021

2.4. MEASUREMENT AND REGULATION OF LIQUID FLOW

A submersible electronic diaphragm pump was used to deliver liquid from a container to the nozzles for all laboratory experiments. A variable voltage generator was used to regulate this pump, giving good control over flow rate. Tolerance was approximately +/- 8 %

Flow rates across the atomisers were monitored using an electronic balance linked to a computer. The computer calculates flow rate by dividing the rate of liquid weight change by liquid density (Bateman, 1989).

2.5. MEASUREMENT OF ROTATION RATE

An inductive pickup tachometer was used to monitor the rate of rotation for the atomisers during all AU8000 experiments. This comprises a grease nipple mounted on the atomiser hub, connected to an inductive transducer which detects pulses caused by the atomiser rotation. A logic device gives a readout in rpm on an LED screen.

The unloaded rotation rate of the cupped spinning disc and slotted rotary drum atomisers was monitored using an optical tachometer, Radio Supplies model TM-2011, which agreed with the inductive pickup tachometer by within +/-2% (Table 2.8).

Table 2.8. Comparison of AU8000 rotation rates measured by optical and inductive pickup tachometers.

Rotation rate measured by optical tachometer (rpm)	Rotation rate with inductive pickup tachometer (rpm)
13000	12963
11000	11080
9000	8974
7000	6982
5000	4993
3000	2997

2.6. MEASUREMENT OF DROPLET SIZE SPECTRA

Droplet size spectra may be measured by counting the number of droplets within a series of size ranges. Measurement techniques may be intrusive or extrusive. Intrusive techniques require the insertion of a solid probe into the spray. The interference effect caused should be quantified and minimised. Most intrusive techniques involve the collection of a sample of spray on a suitable surface such as a magnesium oxide coated slide (May, 1950) which is analysed using a microscope. Non intrusive techniques include imaging, for example by photography (Dombrowski and Hooper, 1962) or holography (MacLoughlin and Walsh, 1978), and optical techniques including light scattering. All laboratory droplet size measurements in this study involved the Malvern light scattering system. Field droplet size measurements were carried out using magnesium oxide coated slides.

DROPLET SIZE PARAMETERS

Several parameters have been used to describe droplet size spectra. No single parameter can completely describe a droplet size spectrum. One of the most widely used parameters for describing droplet diameters of agricultural sprays is the Volume Median Diameter (VMD). This is the droplet diameter which divides the spray into two equal parts by volume.

The Volume Average Diameter (VAD) is less widely used than VMD. VAD, the mean diameter of droplets from a spray, is determined by dividing the total liquid volume by the number of droplets atomised.

The maximum droplet diameter in a spray (Dmax) has been used by many workers to indicate the upper size limit of a droplet size spectrum (Walton and Prewett, 1949; Friedman et al, 1952). Maksymiuk (1964) described the use of Dmax to estimate the VMD from the 5 largest droplets measured in a sample. The minimum droplet size is not normally given, mainly because it is largely determined by the lower size capability of the measurement technique used.

The number median diameter (NMD) divides the spray into two equal parts by number. NMD is useful for deriving the VMD:NMD ratio to give some indication of the spread of the droplet spectrum. A value of 1.0 indicates a monodisperse distribution (Johnstone, 1978); increasing values suggest increasingly broad droplet spectra. It has been suggested that CDA requires a VMD:NMD ratio not exceeding 1.4 for droplet sizing using MgO slides (Johnstone, 1978; Matthews, 1979), and not exceeding 2.0 for Malvern PSA data (Matthews, personal communication).

Several other parameters have been used to express the spread of drop sizes in sprays. Tate (1982) proposed a droplet uniformity index where

$$\text{Droplet uniformity index} = \frac{\eth\ V_i(D_{0.5}-D_i)}{D_{0.5}}$$

D_i is the *midpoint of size class i and V_i is the volume fraction in the size class. This index indicates the spread relative to the VMD and takes into account all size classes.

Relative span is a parameter which is often used to indicate the range of drop sizes relative to the VMD. It is usually calculated as follows:

$$\text{Relative span} = \frac{D_{0.9}-D_{0.1}}{D_{0.5}}$$

A relatively narrow range of droplet sizes relative to the VMD is indicated by a small relative span value.

Quartile relative span has been used as an alternative to relative span (Parkin and Siddiqui, 1990), where:

$$\text{Quartile relative span} = \frac{D_{0.75} - D_{0.25}}{D_{0.5}}$$

The relative width of a droplet spectrum may also be described by the relative proportion of droplets occuring in a few adjacent size bands. Bals (1983) suggested that CDA requires at least 80 percent of droplets to occur in three Malvern size bands, representing a two-fold increase in droplet size.

The percentage of droplets occuring within the desired size range for a given application is a useful parameter of spray suitability for that application. Droplets with diameter less than approximately 35-40 μm have a relatively low impaction efficiency upon Spodoptera exempta larvae, maize and grass leaf surfaces (Lake, personal communication 1991), whilst droplets with diameter larger than approximately 100 μm contain relatively large volumes of liquid but do not necessarily have higher impaction efficiencies with target surfaces (Matthews, 1979). The term 'VO' was used to describe the percentage volume of the total spray contained by droplets in the size class 40-100 μm, considered most suitable for Spodoptera exempta control.

MALVERN PARTICLE SIZE ANALYSER

DESCRIPTION OF APPARATUS AND DATA ANALYSIS

There are several Particle Size Analysis (PSA) instruments available for measuring pesticide sprays. According to Watson and Tech (1985), laser diffraction particle sizing was first used for the analysis of spray droplets in the late 1970's. The Malvern ST1800 PSA (Malvern Instruments Ltd., Malvern, England) has been used for the analysis of droplet size spectra from many atomiser types, including hydraulic nozzles (Combellack and Matthews, 1981; Arnold, 1983) and hand-operated spinning disc atomisers (Bateman, 1989). Accuracy is stated by the manufacturer to be within 4 % for mean diameters calculated using the Rosin Rammler model.

The Malvern PSA instrument utilises a Helium-Neon laser which passes through a beam expander to form a collimated beam. The droplet cloud under analysis is sprayed across the beam within the measurement region. Scattered light is collected by a Fourier transform lens and detected on a 32 element detector. Small droplets forwardly scatter the light to produce diffraction patterns with large scatter angles. The scatter angle decreases with increasing droplet size. The intensity of scattering is a function of the concentration by volume.

Each analysis in this study comprised a background measurement without spray droplets present and a signal measurement whilst spraying. A measured light intensity distribution was derived by subtracting the background measurement from the signal data. The resultant measurement was compared by computer with a size distribution to find the 'best-fit' value for deriving a distribution pattern. Particle size distribution functions including Rossin-Rammler, Nukiyama-Tanasawa, normal (Gaussian), square root normal, logarithmic normal and upper-limit logarithmic normal were discussed by Goering and Smith (1978). Model Independent Analysis was used in this study since some droplet size distributions were likely to be bi- or multi-modal. Model Independent Analysis has been favoured by many workers including Bateman (1989) and Jackson and Samuelson (1985). The Malvern data was analysed using the programme 'MSC and DROPDATA' (Bateman, 1989).

The Malvern ST1800 PSA was housed in a cabinet with a fan mounted behind the laser beam to remove droplets, thereby reducing the risk of droplets contaminating the lenses or being re-circulated. As measurements were taken within 50mm. of the atomiser, evaporation effects were very small. Ambient air temperature was 20 to 24°C; air relative humidity was 65 to 77%.

In this study, each reading consisted of 500 scans. Results were derived as means of three replicates conducted with the equipment at slightly different positions relative to the laser beam to sample droplets produced from all atomiser surfaces. The data exhibited a high degree of reproducibility with 5 μm standard error between replicates for the VMD and NMD.

LIMITATIONS OF MALVERN PSA AND POSSIBLE SOURCES OF ERROR

Young (1985) discussed some limitations of Malvern PSA systems for analysing pesticide sprays. The Malvern PSA was originally developed for studying fuel atomisation processes (Swithenbank et al, 1976). It is therefore well suited to relatively high velocity dense sprays, but not to the less dense sprays produced at very low liquid flow rates.

Several lenses are available for measuring different droplet size ranges. If there are droplets in the largest or samllest size classes from measurements with a given lens, it may be necessary to use another lens to account for droplets which might not be accurately accounted for with a single lens. A lens with a focal length of 799mm. was used for this study. Whilst this will measure droplet diameters up to at least 1500um, droplets of diameter less than 15um are not accounted for.

Hirleman and Dodge (1985) observed a 27 percent variation in mean diameter measurements of a calibration reticle between ten uncalibrated Malvern PSA instruments. This is attributed mainly to variations in the responsivity of the photodiode detectors and can be avoided by calibration. The Malvern instruments used in this study have been calibrated using reticles (Dodge, 1984).

The problem of multiple scattering was discussed by Lefebvre (1989). At high spray densities, light scattered by a drop may be scattered by other drops before reaching the detector. This will give rise to errors in the size distribution computations. Hamadi and Swithenbank (1986) reported a correction procedure for measurements involving multiple scattering.

Malvern PSA instruments contain highly polished lenses which must be correctly aligned and clean whilst measurements are being taken. On several occasions in this study, the lenses became contaminated with spray, giving rise to erroneous measurements. Contamination is often indicated by larger-than-expected subsequent background readings, or by data sets suggesting the presence of droplets in the largest size band, when it is obvious that such droplets are not present in the spray. In such cases, the data sets were discarded and the experiment repeated.

MAGNESIUM OXIDE-COATED GLASS SLIDES

Magnesium oxide coated slides were prepared by burning 20 cm of magnesium ribbon beneath the centre of glass slides as described by May (1950). An advantage of this intrusive technique include the almost constant spread factor of droplets of various liquids upon impaction with the magnesium oxide layer. For droplets of diameter 20 to 200 μm, the spread factor has been found to be approximately 1.16 (May, 1950). Slides can be rapidly prepared and analysed in the field. Slides in this study were returned to the laboratory and analysed using a microscope fitted with a Porton graticule.

A major disadvantage is that there is a relatively high degree of subjectivity in the sizing of droplets. Even where image analyser systems are used, the operator can choose fields of inspection. Droplets impacting at different angles will give different stains on the slides. Large droplets may bounce and shatter upon impact producing smaller droplets. All measurements in this study were taken by the same operator to minimise possible subjective variations.

Whilst both the Malvern PSA with a 799mm focal length lens and magnesium oxide slides cannot accurately size droplets with diameter less than 15 μm, the Malvern is more accurate for measuring droplet diameters between 200 and 1499 μm. Droplets with diameters larger than 200 μm tend to shatter upon impact with magnesium oxide-coated slides (Matthews, 1979), making their size determination less accurate. Malvern PSA instruments cannot easily be used in the field where sunlight and electricity availability cause problems.

2.7. OBSERVATIONS OF ATOMISATION USING STROBOSCOPE.

With the atomisers mounted in a dark cabinet, a stroboscope was used to observe the liquid atomisation at the disc, drum and cage peripheries at different flow and rotation rates.

2.8. DROPLET DEPOSITION IN GRASS AND MAIZE CANOPIES

It is often difficult to compare the field performance of sprays with characteristics observed in the relatively controlled laboratory environment (Merritt, 1989). Meteorological conditions influence droplet size by affecting evaporation rates. Evaporation rates increase with increasing liquid volatility, increasing wind speed, increasing air and liquid temperature, decreasing relative humidity, and increasing airborne time duration. Droplet sizes were measured in the laboratory within a fraction of a second after atomisation, whilst field measurements were taken after droplets had been airborne for periods of a few seconds to several minutes. It was therefore important to measure meteorological conditions to consider possible evaporation effects. A Wessex Weather Logger (Wessex Power Technology, Poole, UK) was used to monitor ambient air temperature, relative humidity, windspeed and wind direction whilst spraying in the field. Meteorological conditions varied during the trials with mean windspeed approximately 1.5 - 2m m/sec in variable directions but always approximately perpendicular to the spray line. Ambient air temperatures ranged from 20 to 26.2°C and relative humidity was 55 to 76% (Appendix 1).

A 5 HP motorised knapsack mistblower fitted with a Micronair AU8000 atomiser was used to spray a 2.4 % w/v ULV cypermethrin formulation containing 1 % w/v Kenawax blue dye (ICI) as a tracer. Flow rate was determined and the forward speed was adjusted to apply 1 l/ha over a selected swath.

Trials were carried out with the mistblower carried on the operator's back, with the outlet at a height of 1 m above the ground. The mistblower was also mounted on the back of a Landrover and operated with the outlet at a height of 2 m above the ground.

Kromekote cards (3 X 1 cm) were attached to clothes pegs attached to vertical metal poles. The papers were folded along the long central axis to produce horizontal and vertical sampling surfaces. All samples were placed at 0.3 m above the ground, since this was the maximum height at which *Spodoptera exempta* larvae occurred in the trial sites. Papers were also placed horizontally on the ground. Sampling sites were at the following distances at 90 degrees downwind of the application line: 0m, 2m, 5m, 10m, and then at 10m intervals to 110m. Differences in droplet densities deposited at the three sampling positions (horizontal and vertical papers at 0.3 m height and on the ground) and at different distances downwind were compared using two-way analysis of variance.

The droplet spectra were sampled on 6 mm wide magnesium oxide coated slides (May, 1950) mounted on rotary samplers (Lee et al, 1978; Thornhill, 1979; Cooper et al, 1987) placed at the first four sampling sites.

It is important to obtain a representative sample when determining droplet size spectra using the magnesium oxide coated slide method. Two hundred droplets on each of two slides collected from each sampling site were measured in the laboratory using a microscope with a X10 eyepiece, X10 objective lens and Porton G12 graticule. Droplets were classified into size classes which were corrected for collection efficiency which varies with target speed, wind speed and droplet diameter (Yeomans, 1949; Carlisle and Rathburn, 1970; Cooper et al, 1987).

2.9. CONTROL OF SPODOPTERA EXEMPTA LARVAE

Concurrently with assessments of droplets (section 2.7), the numbers of live and dead Spodoptera exempta larvae were recorded at each sampling location using 0.5 X 0.5 m quadrats before and at 6, 12 and 24 hours after each treatment. Percentage larval mortality was calculated as the proportion of recorded larvae which were dead. This allowed concurrent assessments of droplet densities and larval mortalities against downwind distance. By making several passes under different conditions it was intended to be able to predict relevant swath widths from both droplet and larval mortality data.

2.10. DROPLET DEPOSITION IN TREE CANOPIES

The aim of these trials was to compare spray coverage of Toronja grapefruit trees, Citrus paradisi, when sprayed using an axial fan sprayer fitted with hollow cone ceramic nozzles and Micron X1 atomisers.

For each trial, four different grapefruit trees were selected at random at Buena Vista, La Ceiba, Honduras. The test liquid comprised water with 0.1 % v/v Adsee surfactant (ICI distributor, Tegucialpa, Honduras) and 0.5 % w/v Tinopal CBS-X fluorescent tracer. One side of an FMC 1087 speed sprayer was fitted with 12 X1 atomisers; the other side was fitted with 20 hollow cone ceramic nozzles (Fig 2.5).

Fig. 2.5. Atomiser positions on FMC 1087 air ducts.

X1 atomisers							Hollow cone nozzles					
-	-	-	x	-	-	Uppermost duct	-	x	-	x	-	-
x	-	-	-	-	-		-	x	-	-	-	-
x	-	-	-	x	-		-	x	x	-	x	-
x	-	-	-	-	-		-	x	x	-	x	-
x	-	-	-	x	-		-	x	x	-	x	-
-	x	-	-	-	-		-	x	-	-	x	-
-	x	-	-	-	-		-	x	-	-	x	-
x	-	-	-	-	-		-	x	-	-	-	-
x	-	-	-	-	-		-	x	-	-	-	-
x	-	-	-	-	-		-	x	-	-	-	-
-	-	-	-	-	-	Lowest duct	-	-	x	-	-	-

x atomiser or nozzle position

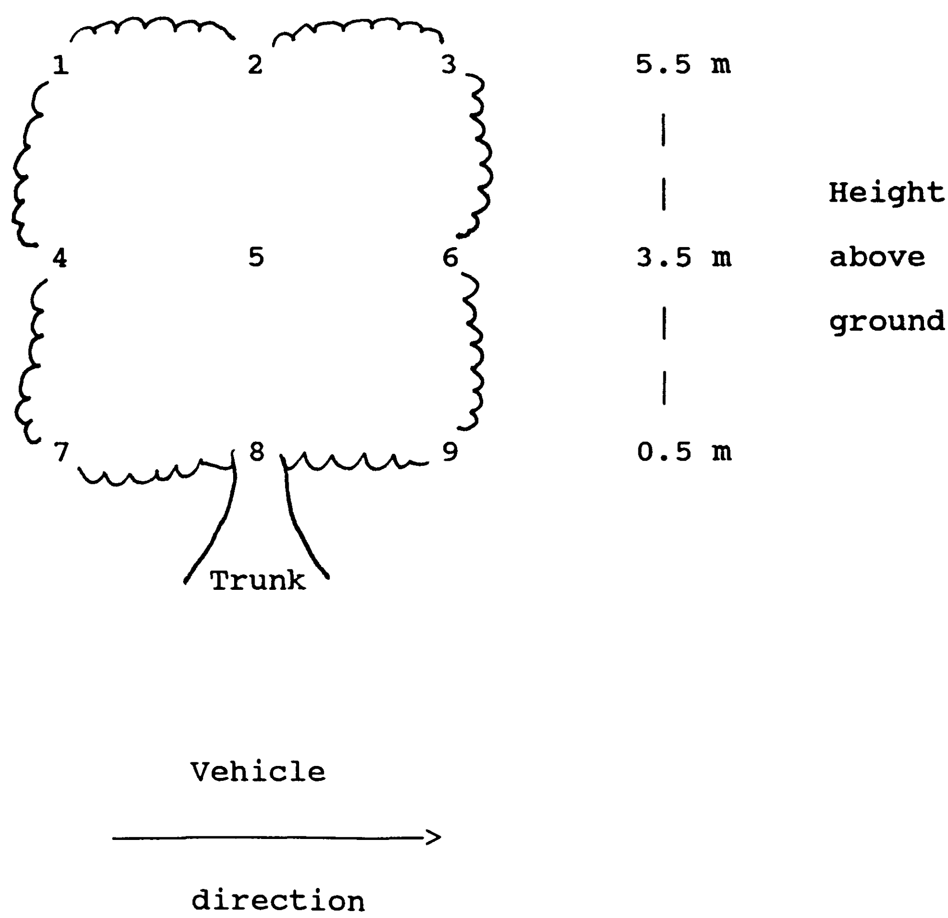
- plugged outlet

Restrictors with different orifice sizes were used to regulate liquid flow to each atomiser to obtain the required volume application rates based on the determined vehicle forward speed of 30 seconds per tree. Flow rates were checked for each atomiser by collecting the liquid throughput in one minute at 8.8 kg/cm^2. liquid pressure. Application rates were as follows: 25.0, 12.5 and 6.0 l/tree. The rotational speed of each X1 was checked with an optical tachometer. Rotation rates varied between 12,000 and 17,000 rpm according to relative airstream velocity which varied from 49 to 87 m/sec. Time of day, meteorological conditions, and vehicle forward speed per tree were monitored during the trials.

Liquid lost from trees was collected in polythene sheeting placed beneath the trees, extending 0.5 m from the sides of the tree canopies. The liquid volume was measured using 1 l graduated cylinders after the cessation of runoff.

To assess spray coverage on leaf surfaces, leaves were collected after spraying from the outer sides of the trees at the positions shown in Fig 2.6.

Fig. 2.6. Sampling positions within grapefruit trees.



Leaves were also collected from the same positions at the central axis of each tree. Ciba-Geigy water-sensitive papers similar to those developed by Turner and Huntingdon (1970) were attached at random orientations to the trunk at 0.3m, 1m, 2m and 5m above the ground. Papers were also attached to leaves at the same sampling positions for some trials to check the accuracy of the fluorescent tracer technique. All samples were analysed in the laboratory. The water-sensitive papers were visually assessed for percentage liquid coverage according to the percentage area of blue bromoethyl blue stain. The leaves were examined under ultra-violet light and a similar assessment was made of percentage cover.

Droplet size spectra were assessed using magnesium oxide coated slides.

Chapter 3

LABORATORY STUDIES

3.1. INTRODUCTION

Since the effects of similar independant variables upon droplet size spectra were assessed for all atomiser types, laboratory results are described for each variable involved.

3.2. RESULTS

3.2.1. LIQUID TYPE, FLOW RATE, ATOMISER ROTATION RATE AND AIRSTREAM VELOCITY

Liquid type and flow rate affected the rotation rates of the atomisers when loaded. The droplet size spectra were affected directly by the liquid type and flow rate and indirectly by the decrease in rotation rate caused by liquid flow.

3.2.2. EFFECT OF LIQUID TYPE AND FLOW RATE UPON ATOMISER ROTATION RATE

MICRON X1 CUPPED SPINNING DISC

The rotation rate of the X1 atomiser in a 116 m/sec airstream decreased with flow rate (Fig 3.1) according to the following equation:

$$N \approx N_o - (1.2.Q^{1.1})$$

(r^2=0.99; df=18)

The rotation rate of the electrically-driven X1 atomiser decreased with flow rate (Fig 3.2) as shown by the following equation:

$$N \approx N_o - [0.00586.N_o^{0.85}.Q^{0.98}]$$

(r^2=0.99; df= 52)

These equations do not take account of liquid physical properties because tests were only carried out with water+Agral.

MICRONAIR AU8000 ROTARY CAGE ATOMISER

In an airstream with a velocity of 116 m/sec, the rate of decrease of rotation rate for the AU8000 atomiser was

Fig 3.1. Rotation rate of Micron X1 atomiser against flow rate of water+Agral. Air velocity = 116 m/sec.

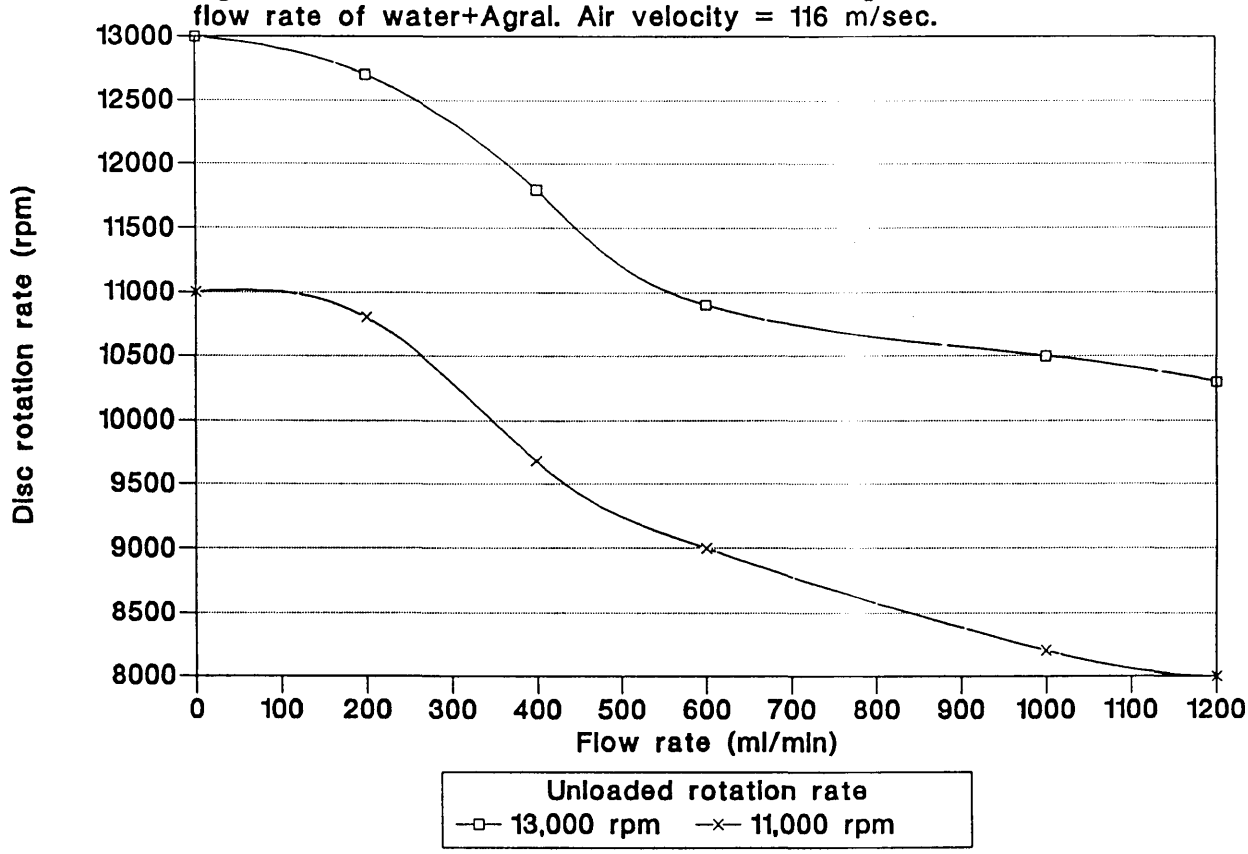
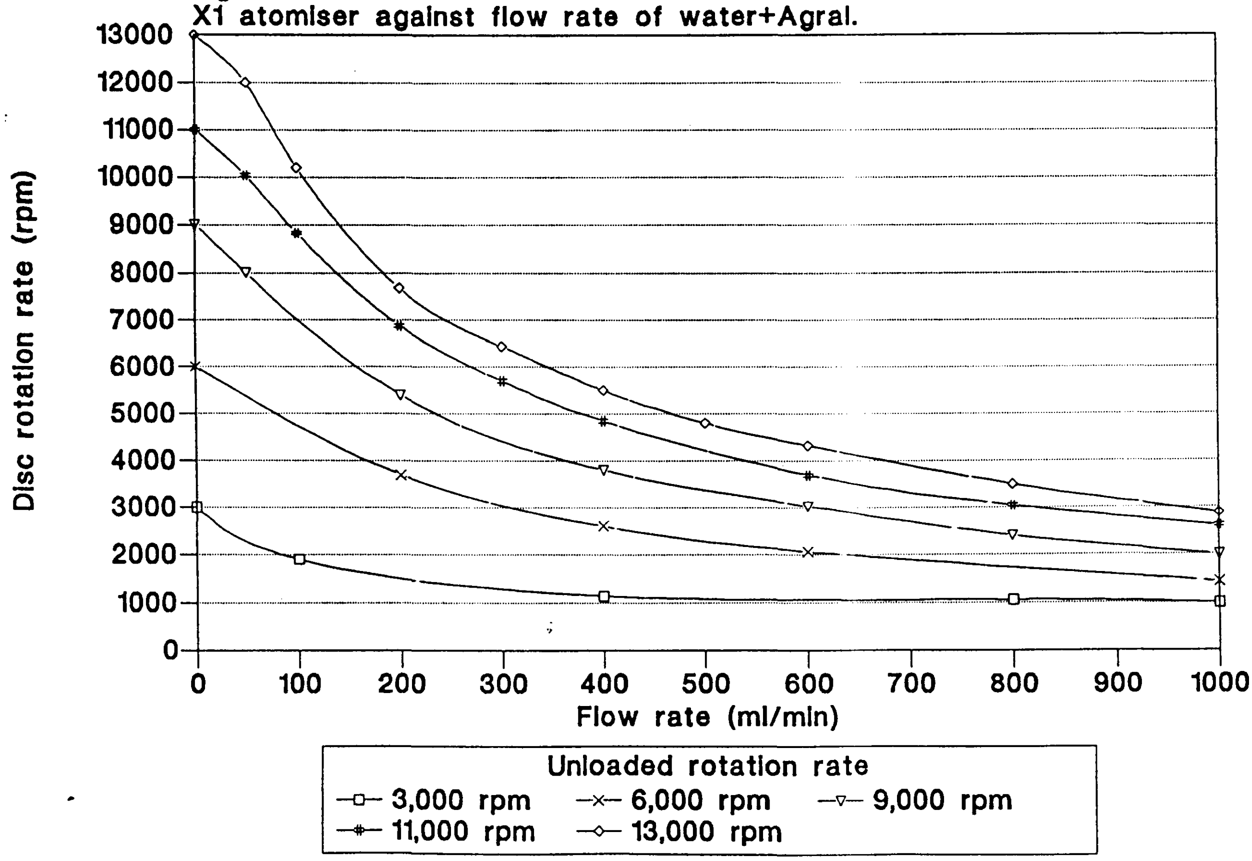


Fig 3.2. Rotation rate of non air-assisted electric motor-driven X1 atomiser against flow rate of water+Agral.



similar for kerosene and Risella but approximately 2 times higher with water+Agral (Fig 3.3).

Loaded atomiser rotation rate (N) was related to the independant variables flow rate (Q ml/min), original unloaded rotary speed (N_o rpm) and fluid density (p kg/l at 20°C) using multiple linear regression analysis of logged variable values. The following empirical equation was developed:

$$N \approx N_o - [0.000016.Q.(N_o^{1.47}).(p^{3.33})]$$

(r^2=0.99; df=68).

SLOTTED ROTARY DRUM ATOMISERS

The rotation rate of the electrically-driven Noric drum number 3 decreased with flow rate of water+Agral (Fig 3.4) according to the following linear equation:

$$N \approx N_o - 0.2Q$$

This equation does not take account of liquid physical properties because tests were not carried out with different liquid types.

Fig 3.3 Loaded rotation rate of AU8000 against flow rate of different liquids in an airstream with a velocity of 116 m/sec.

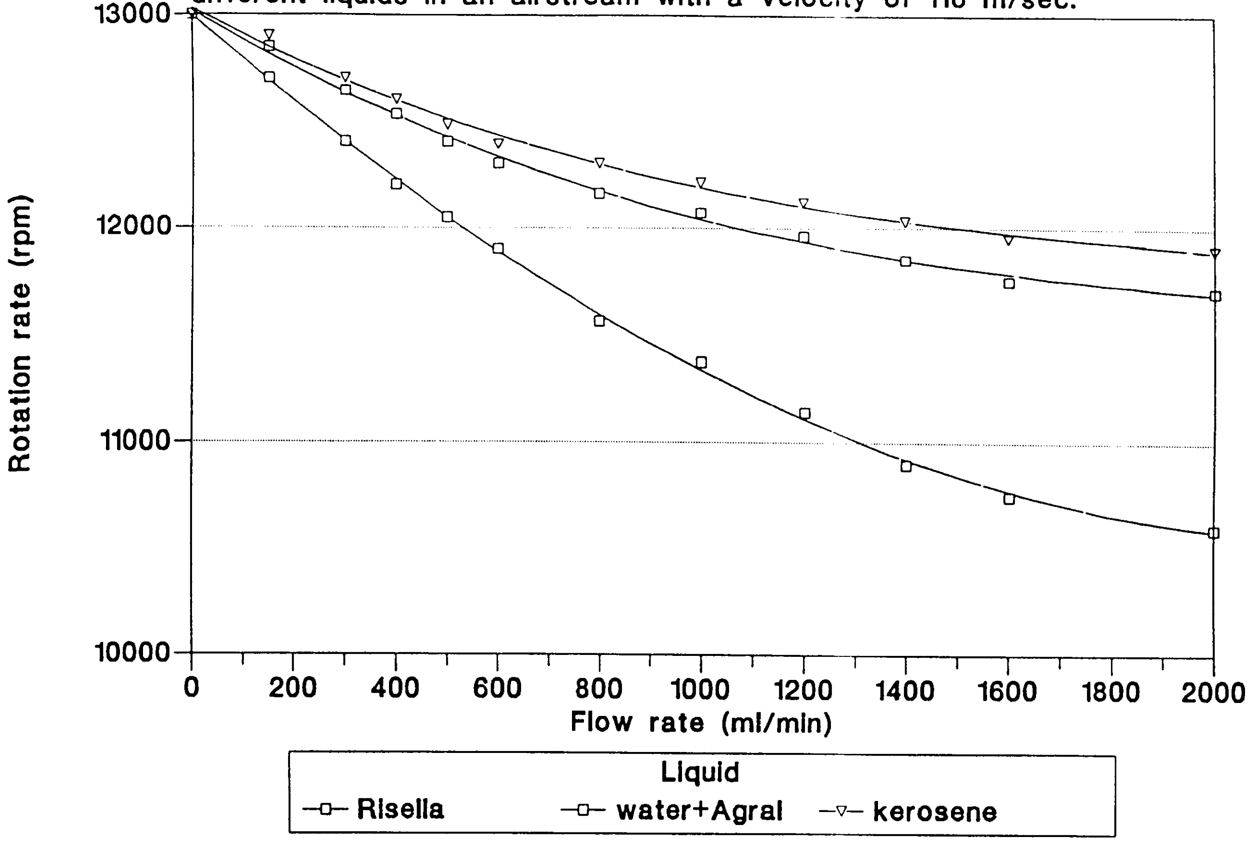
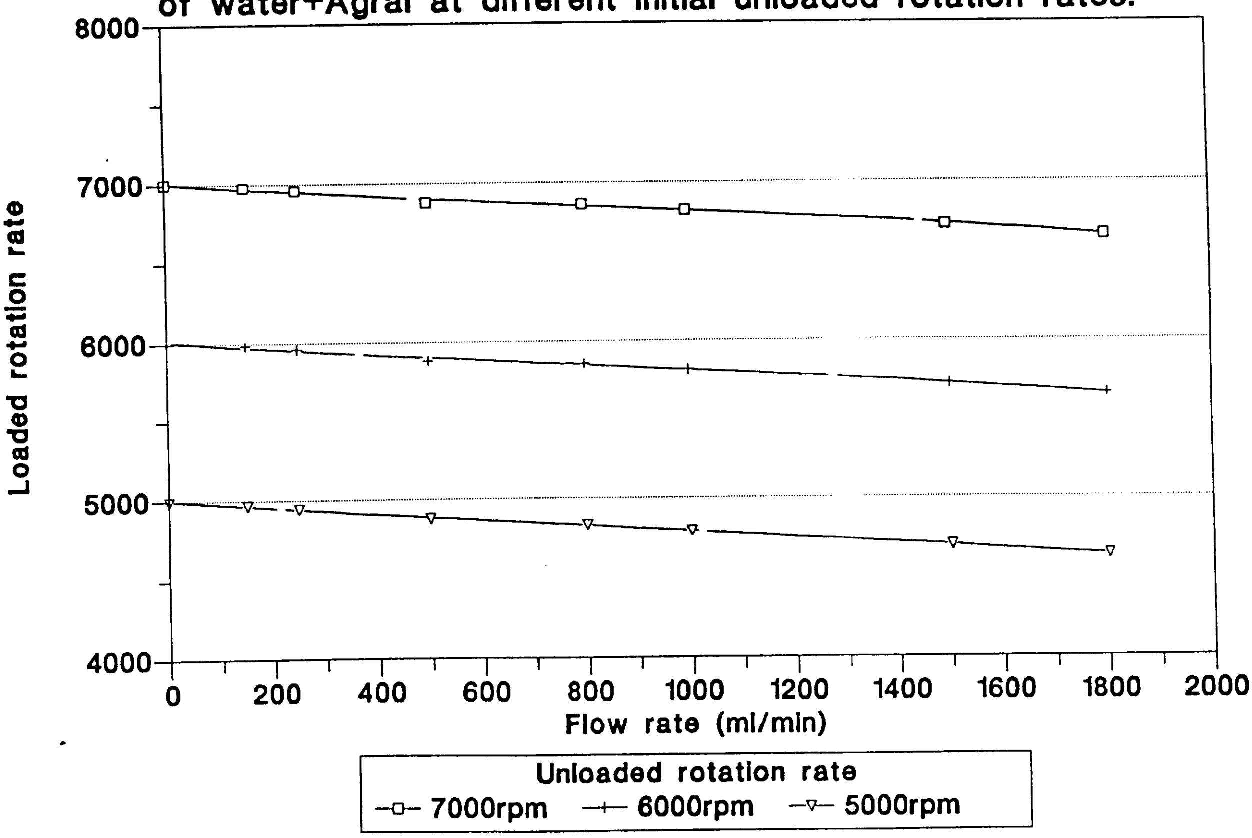


Fig 3.4 Loaded rotation rate of NORIC 7 against flow rate of water+Agral at different initial unloaded rotation rates.



3.2.3. DROPLET SIZE SPECTRA

AIR-SHEAR STRAIGHT JET NOZZLES

The VMD and VMD/NMD ratio increased with increasing flow rate, increasing liquid density (Figs. 3.5 and 3.6) and decreasing airstream velocity (Figs. 3.7 and 3.8). In an airstream with a velocity of 116 m/sec, the VMD and VMD/NMD ratios for Risella decreased with increasing number and surface area of liquid issuing points. The VMD and VMD/NMD ratios were lower for water+Agral than for Risella. Differences in the VMD and VMD/NMD ratio between nozzle types were larger with Risella than with water+Agral. Reliable droplet size data could not be obtained for kerosene at an airstream velocity of 116 m/sec, however at 87 m/sec, kerosene produced the lowest VMD and VMD/NMD ratios at all flow rates. The difficulty in obtaining droplet size data with kerosene at high air shear velocity was due to laser beam displacement or 'beam steering' (Lefebvre, 1989) as the volatile spray was concentrated in a relatively narrow jet (R. Jones, personal communication).

The percentage volume of droplets and cumulative percentage volume were plotted against a $\sqrt{2}$ progression of droplet size class for each liquid sprayed through the air-shear nozzles in an airstream velocity of 87 m/sec (Figs 3.9 to 3.14). The droplet size spectra were bi-modal at a liquid flow rate of 100 ml/min and tri-modal at higher flow rates.

Fig 3.5VMD against flow rate for different liquids sprayed through different straight jet air-shear nozzles. Airstream velocity = 116 m/sec.

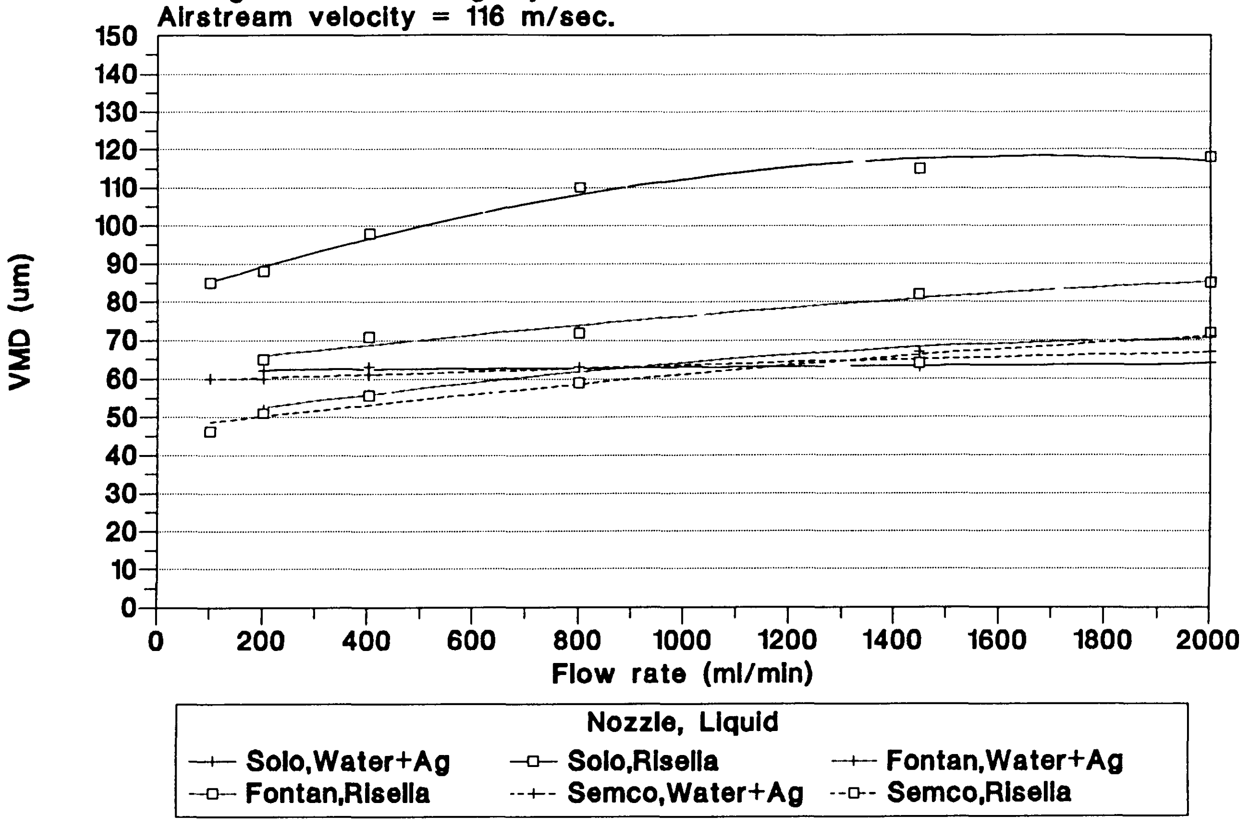


Fig3.6VMD/NMD ratio against flow rate for different liquids sprayed through different straight jet air-shear nozzles. Airstream velocity = 116 m/sec.

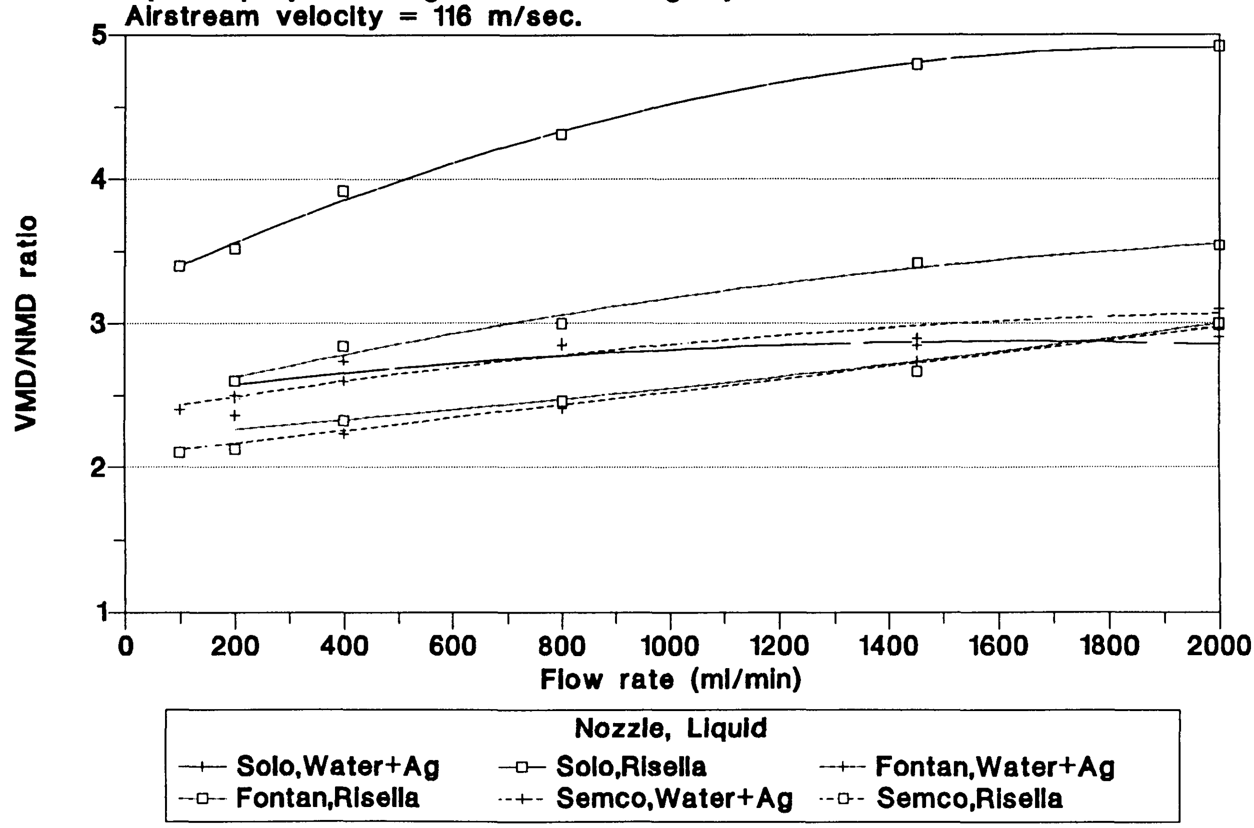


Fig 3.7 VMD against flow rate for different liquids sprayed through different straight jet air-shear nozzles. Airstream velocity = 87 m/sec.

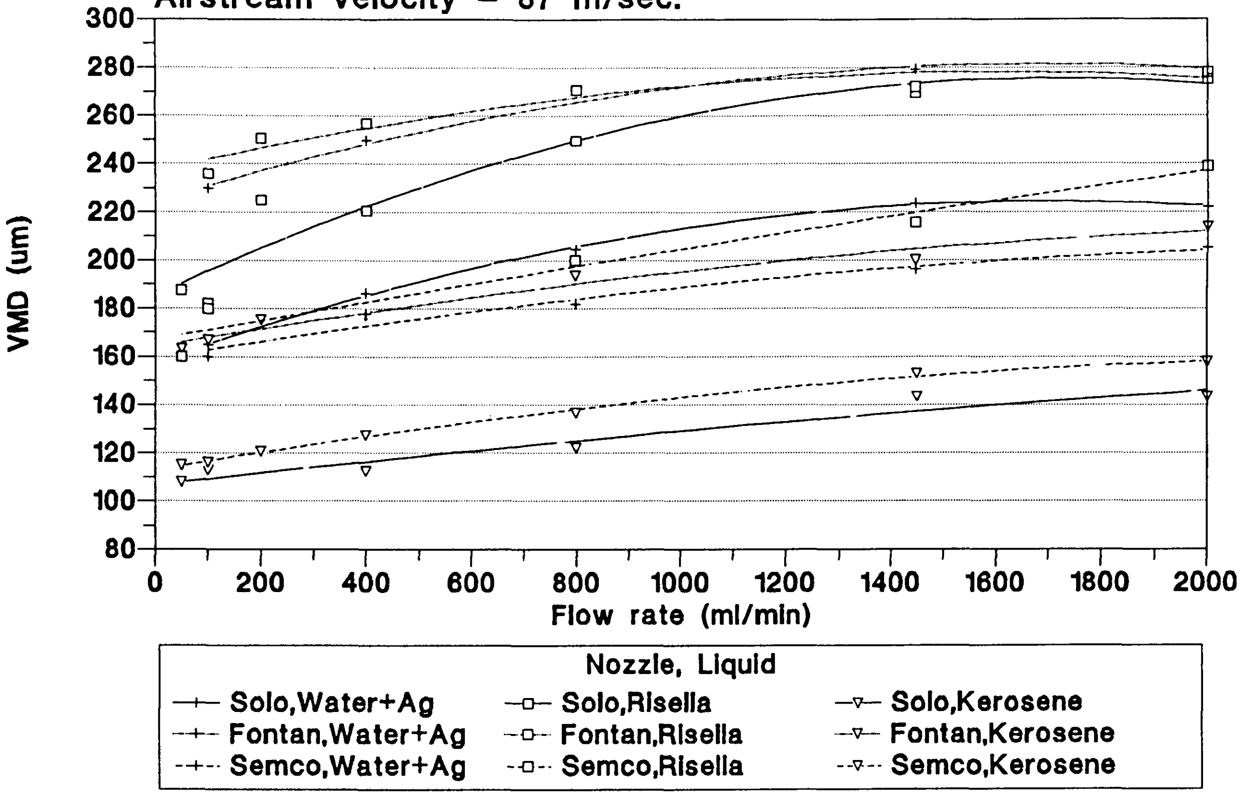


Fig 3.8 VMD/NMD ratio against flow rate for different liquids sprayed through different straight jet air-shear nozzles. Airstream velocity = 87 m/sec.

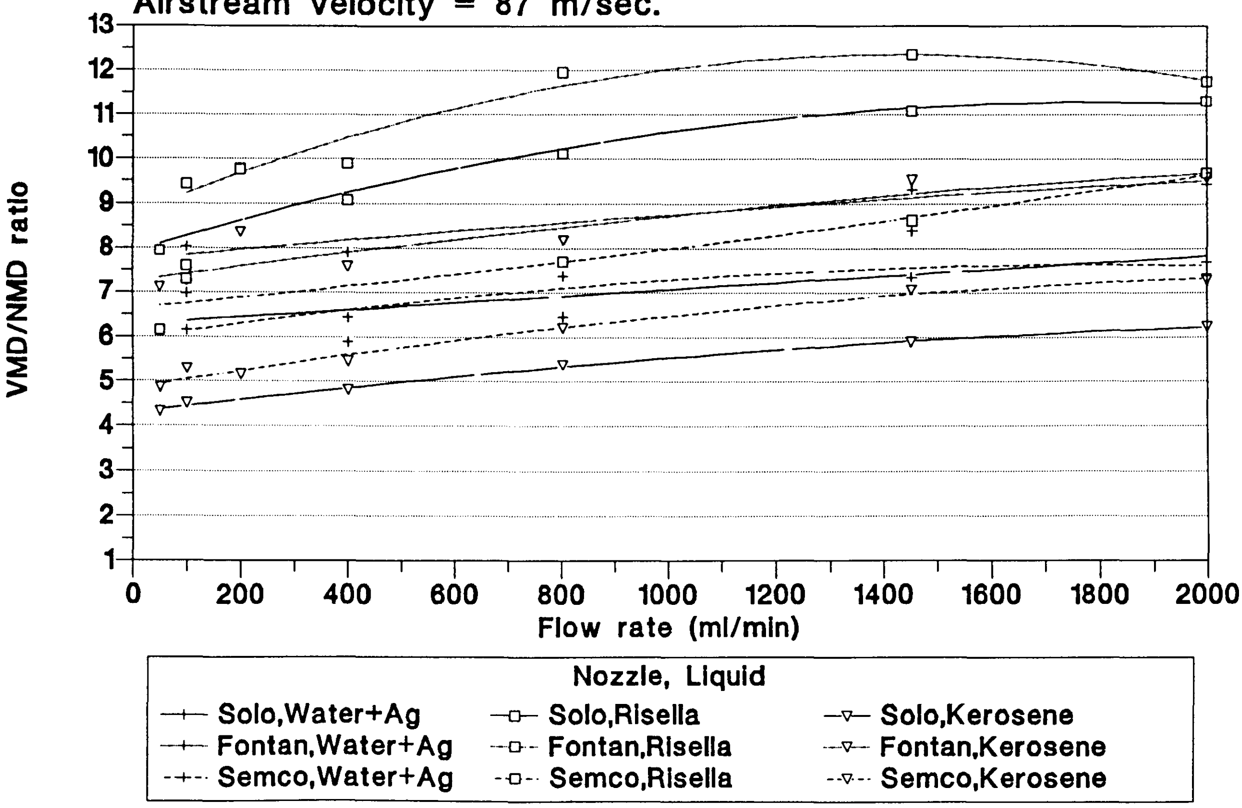


Fig 3.9 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Solo nozzle. Airstream velocity = 87 m/sec.

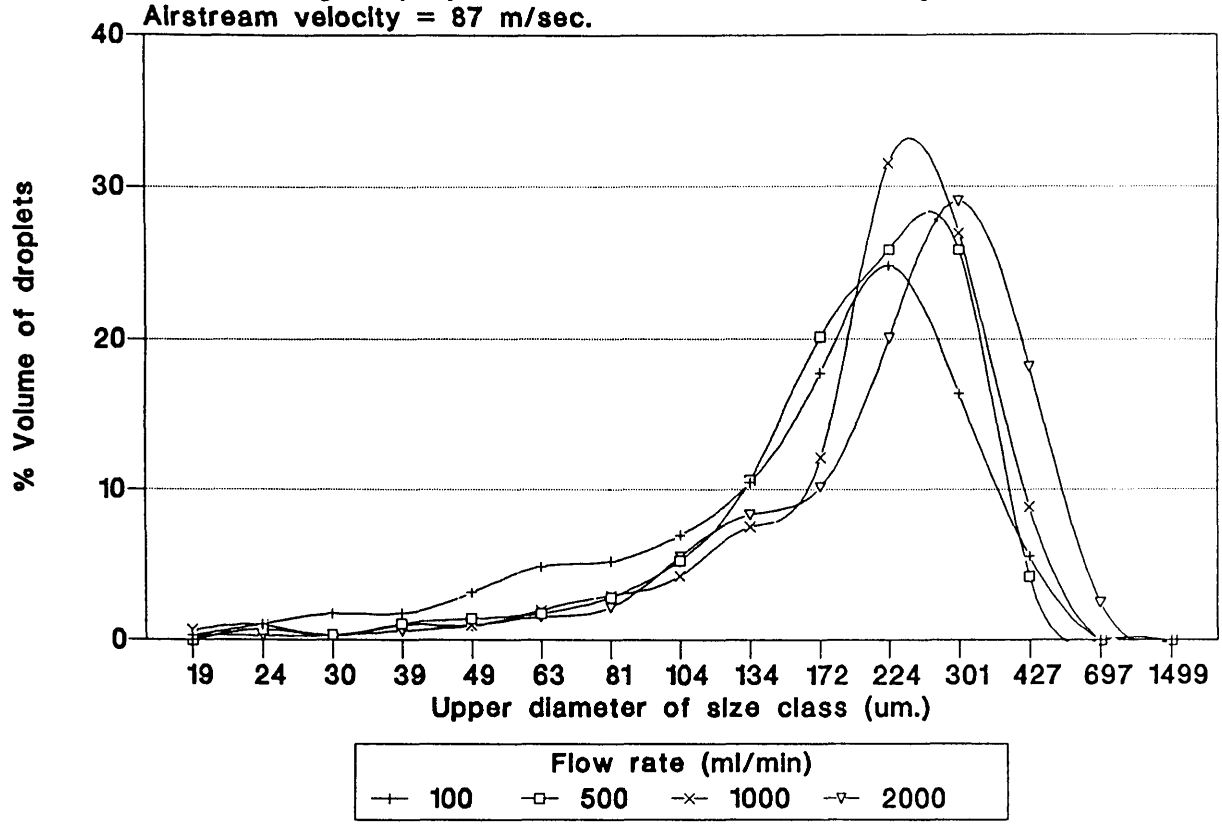


Fig 3.10 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through Solo nozzle. Airstream velocity = 87 m/sec.

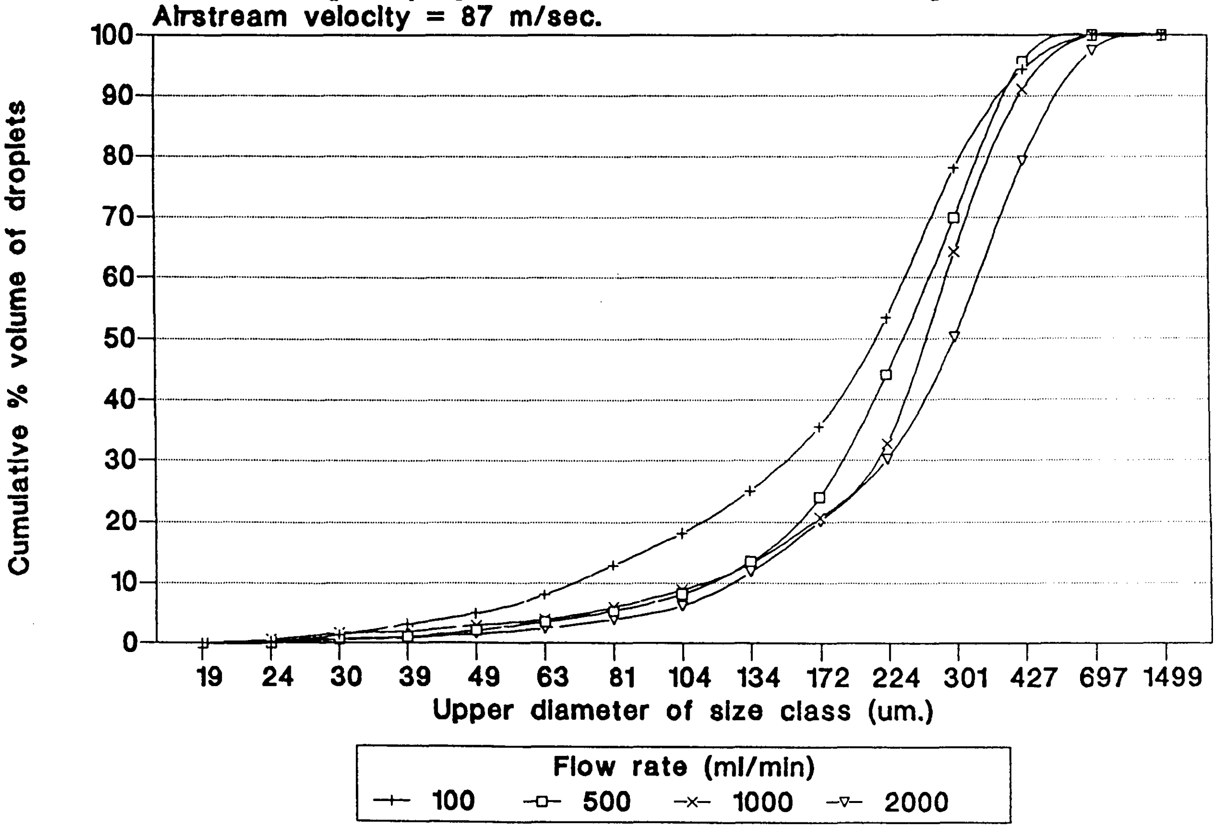


Fig 3.11 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Fontan nozzle. Airstream velocity = 87 m/sec.

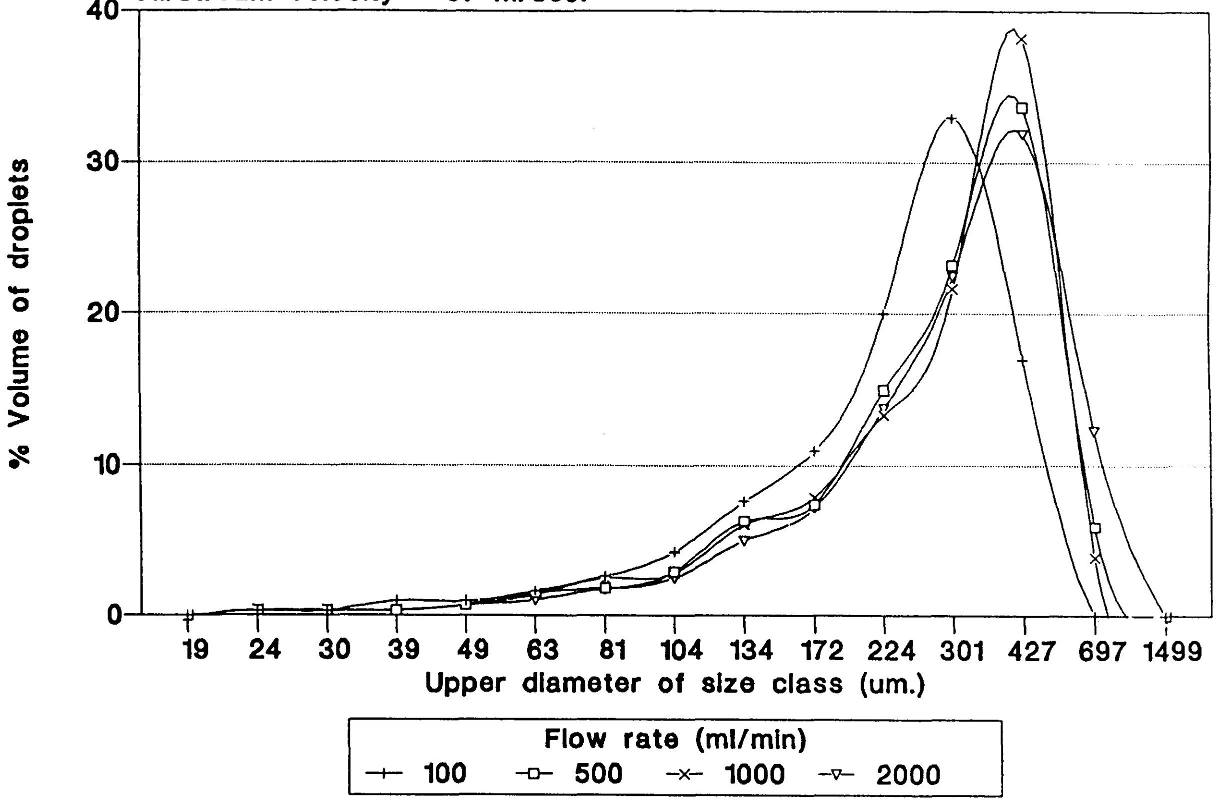


Fig 3.12 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through Fontan nozzle. Airstream velocity = 87 m/sec.

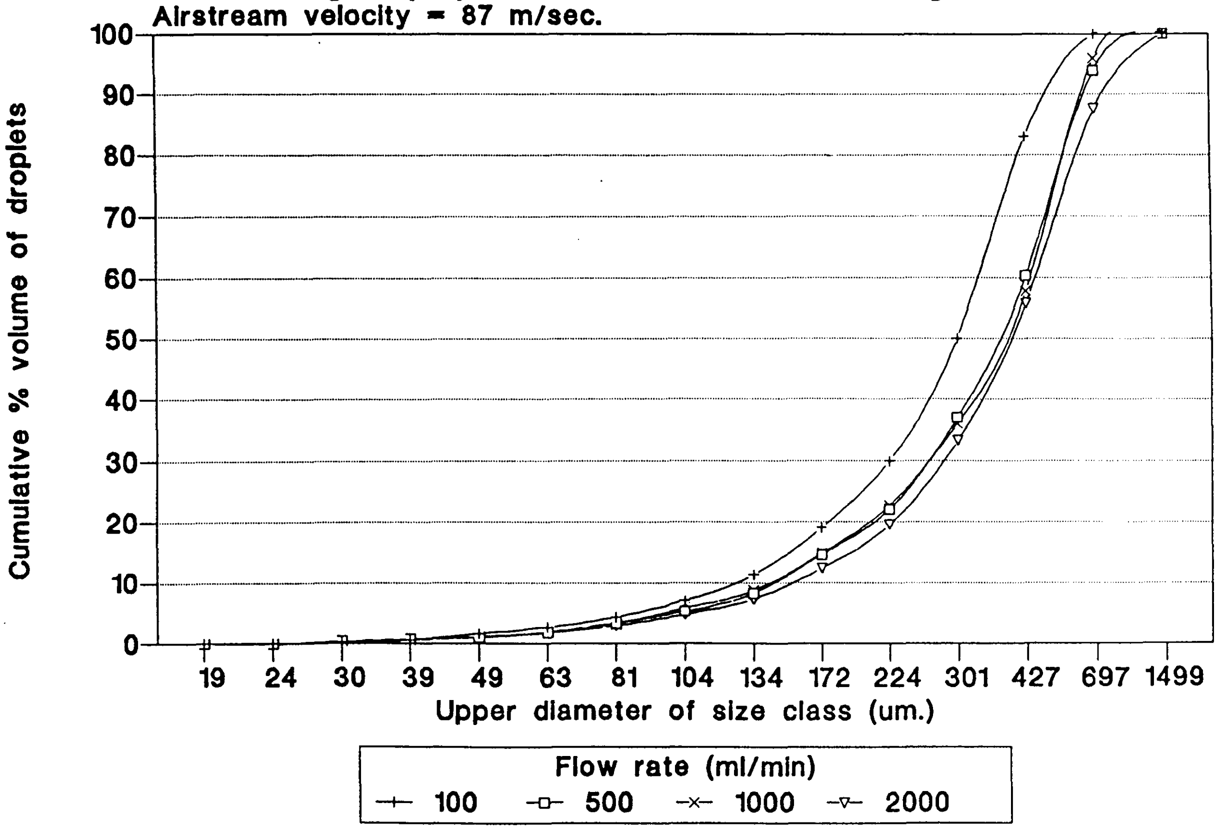


Fig 3.13 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Semco nozzle. Airstream velocity = 87 m/sec.

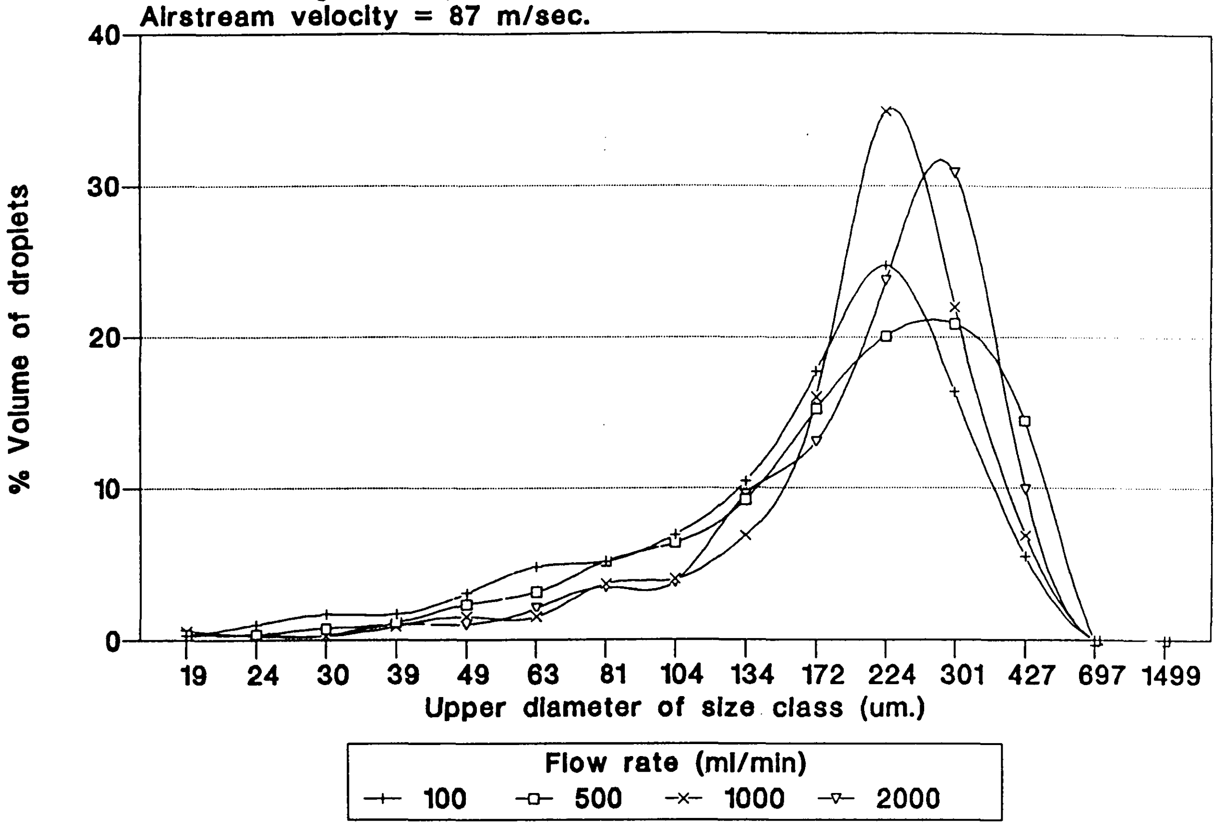
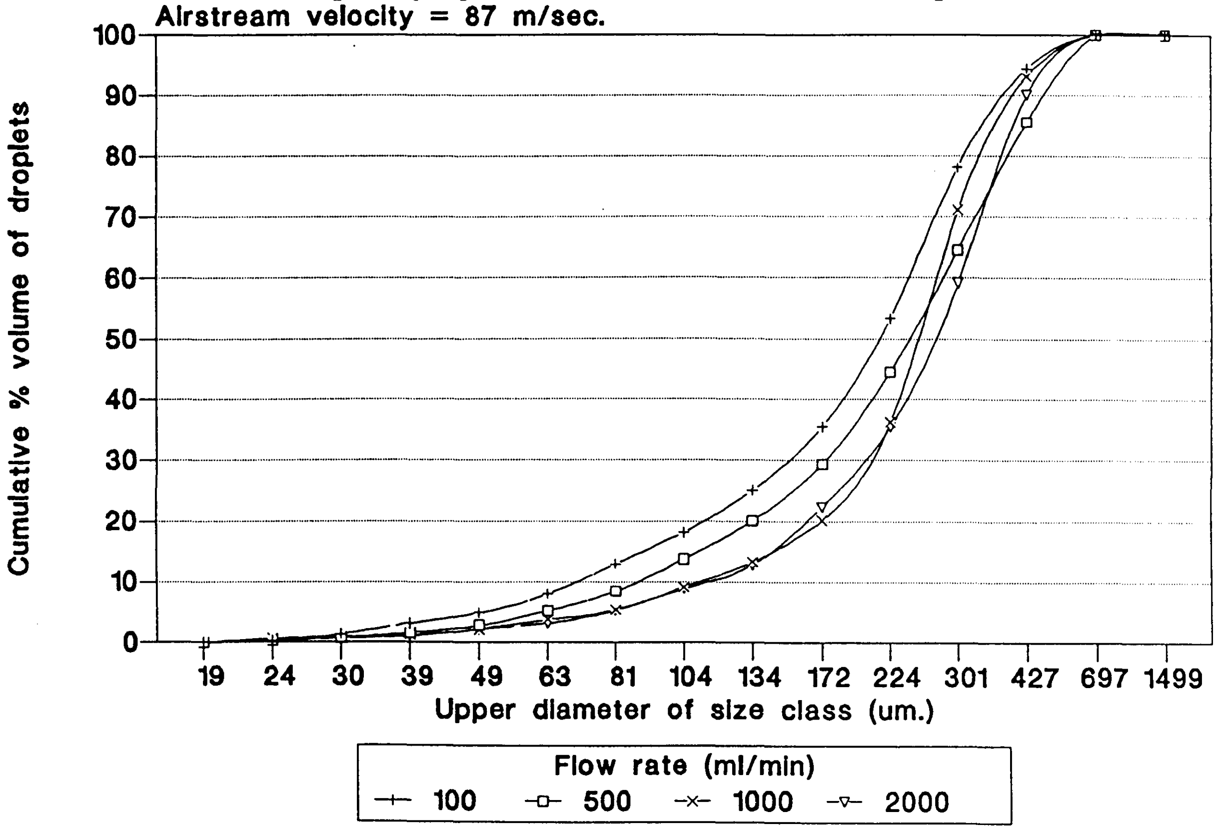


Fig 3.14 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through Semco nozzle. Airstream velocity = 87 m/sec.



CUPPED SPINNING DISC

AIR-ASSISTED X1 ATOMISER

The VMD and VMD/NMD ratios of water+Agral sprayed through the air-assisted X1 increased with higher flow rate, lower airstream velocity and lower disc rotation rate (Figs 3.15 to 3.18).

The volumetric droplet size spectra were generally mono-modal (Figs 3.19 to 3.30). However, at very low flow rates, bi- and tri-modal spectra were sometimes observed due to relatively large numbers of droplets with diameter less than 30 μm. This occurred at Q=100 ml/min, U=87 m/sec, N=13,000 rpm; and Q=500 ml/min, U=87 m/sec, N=3000 rpm. An increase in the airstream velocity caused a displacement of the volumetric droplet size distributions towards the smaller size bands.

NON AIR-ASSISTED X1 ATOMISER

Although there was a similar trend of increasing VMD and VMD/NMD ratio with higher flow rate for the air-assisted (Figs 3.15 to 3.18) and non air-assisted (Figs 3.31 and 3.32) X1 atomisers, the latter increased at a higher rate with changes in liquid flow and disc rotation rate. At flow rates below 200 ml/min, the VMD and VMD/NMD ratio values for a given rotation rate were similar for the X1 atomiser

Fig3.15 VMD against flow rate of water+Agral sprayed through X1 atomiser rotating at different rates. Airstream velocity = 116 m/sec.

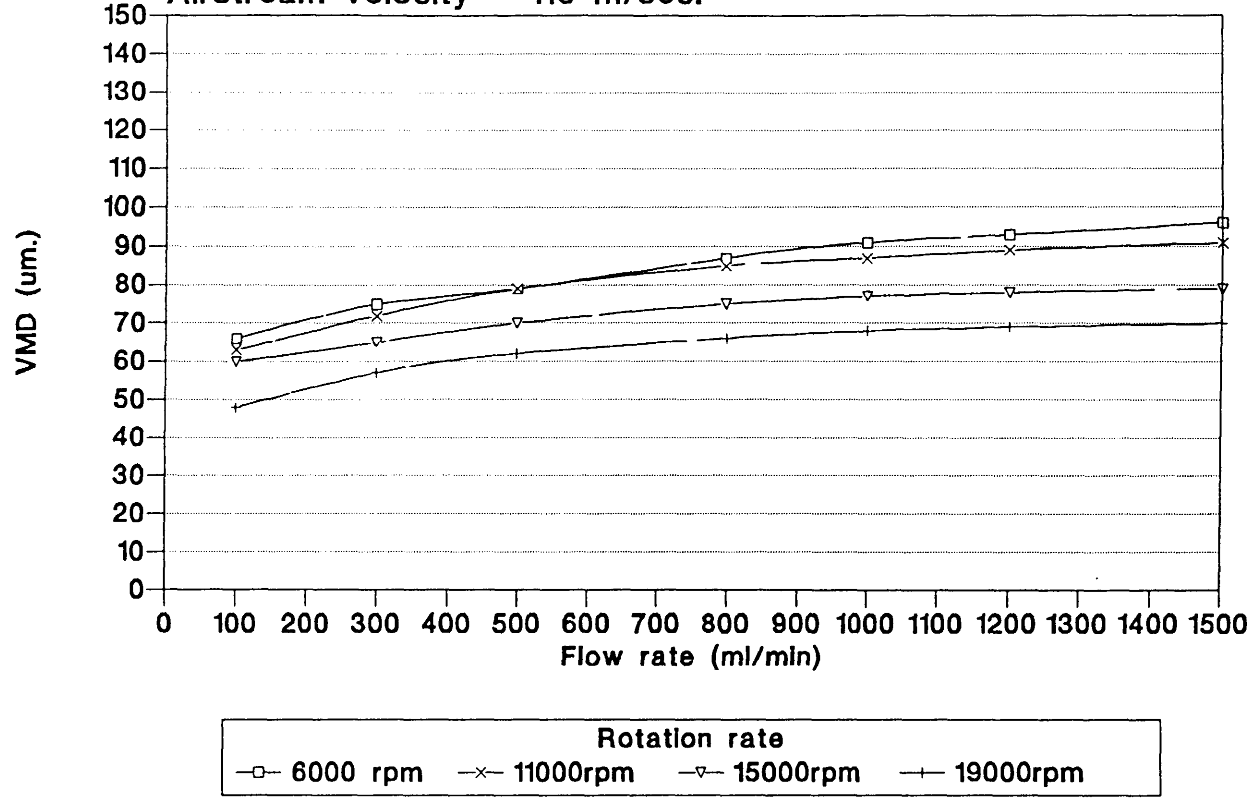


Fig3.16 VMD/NMD ratio against flow rate of water+Agral sprayed through X1 atomiser rotating at different rates. Airstream velocity = 116 m/sec.

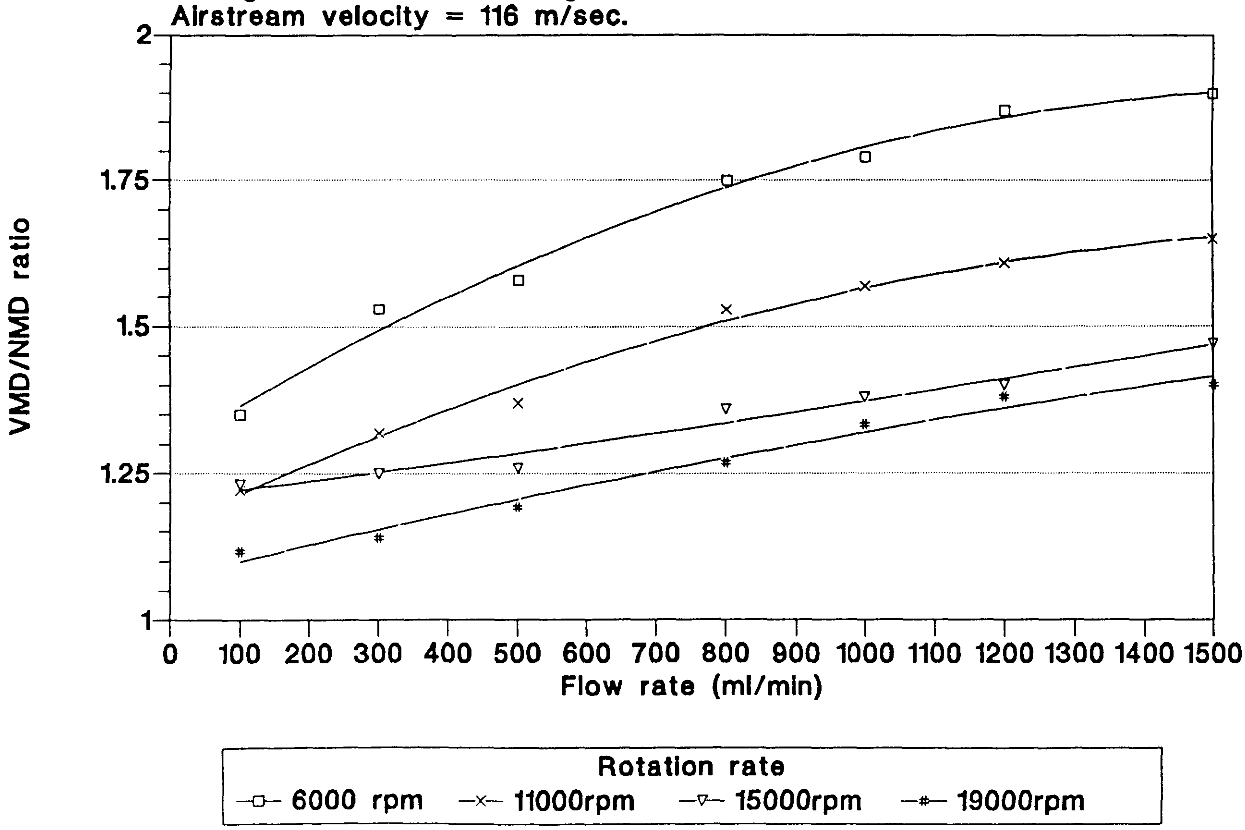


Fig3.17 VMD against flow rate of water+Agral sprayed through X1 atomiser rotating at different rates. Airstream velocity = 87 m/sec.

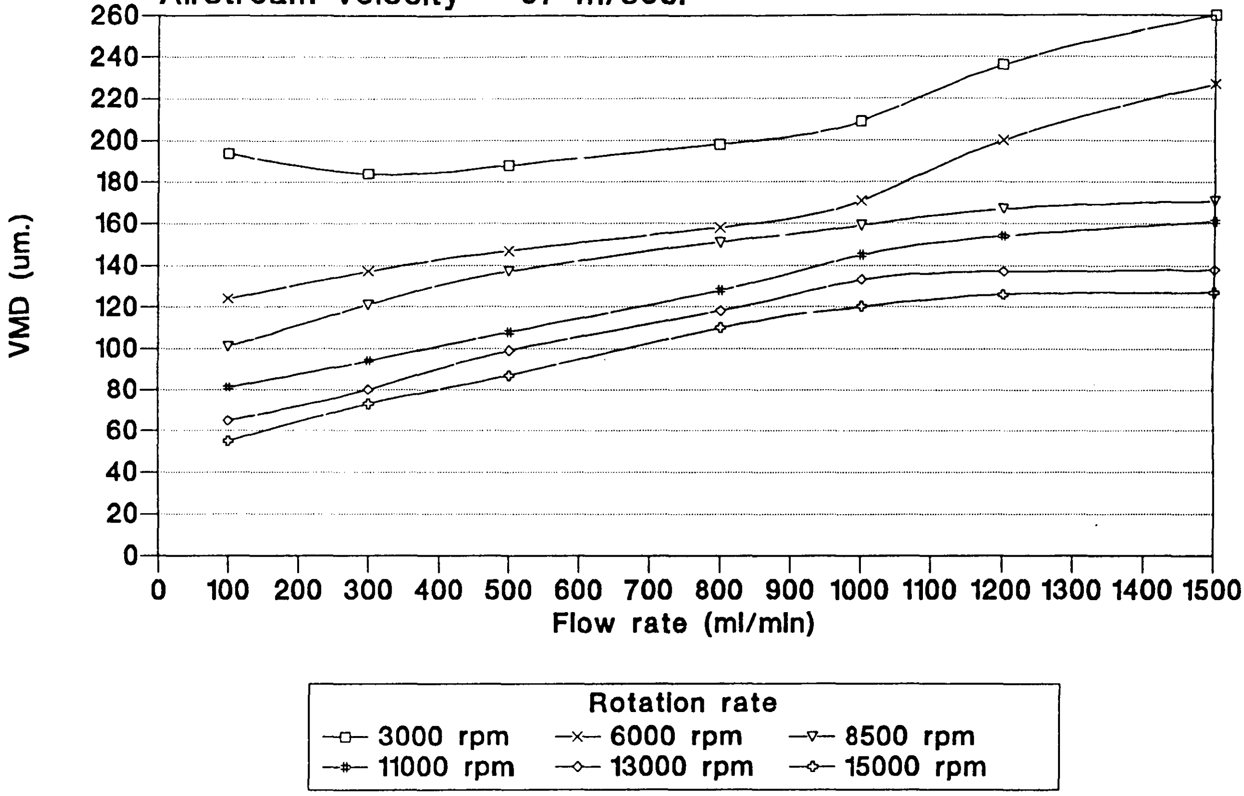


Fig3.18 VMD/NMD ratio against flow rate of water+Agral sprayed through X1 atomiser rotating at different rates. Airstream velocity = 87 m/sec.

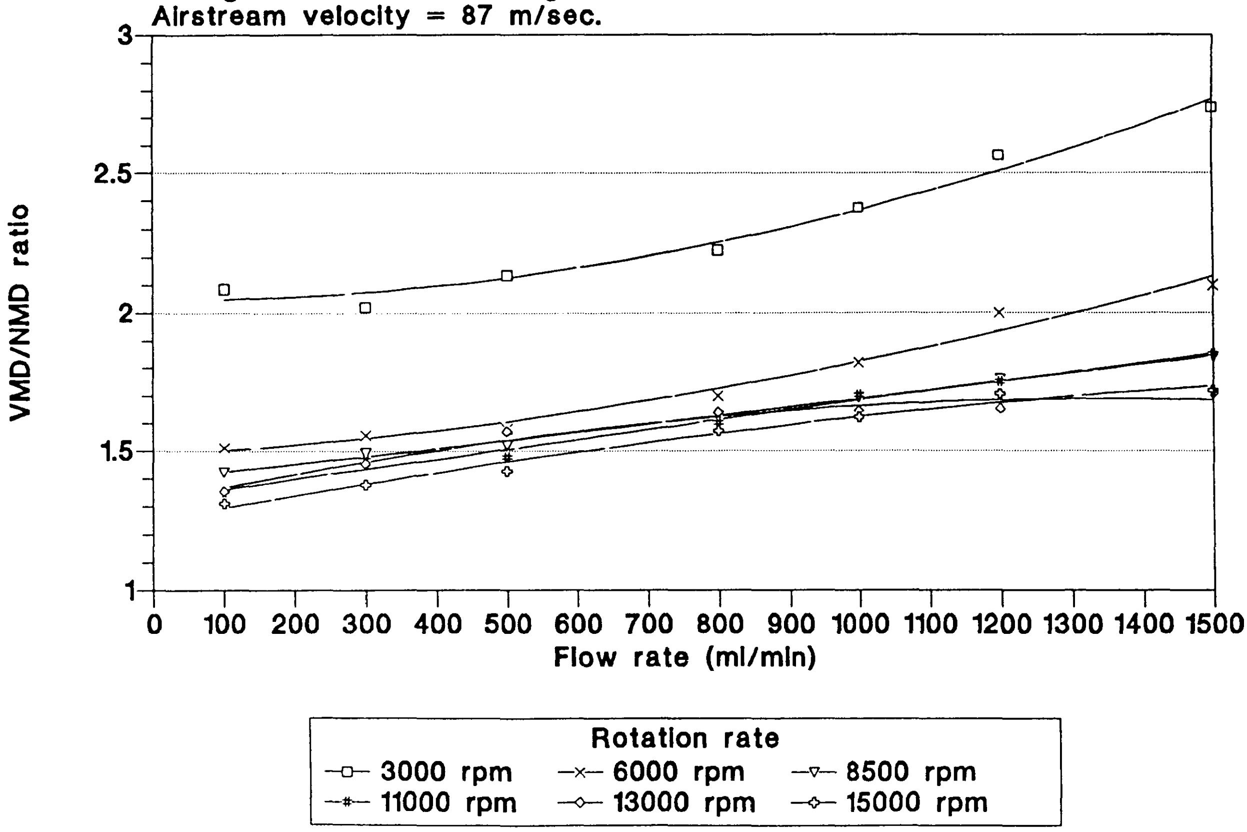


Fig 3.19 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 87 m/sec; rotation rate=3,000rpm.

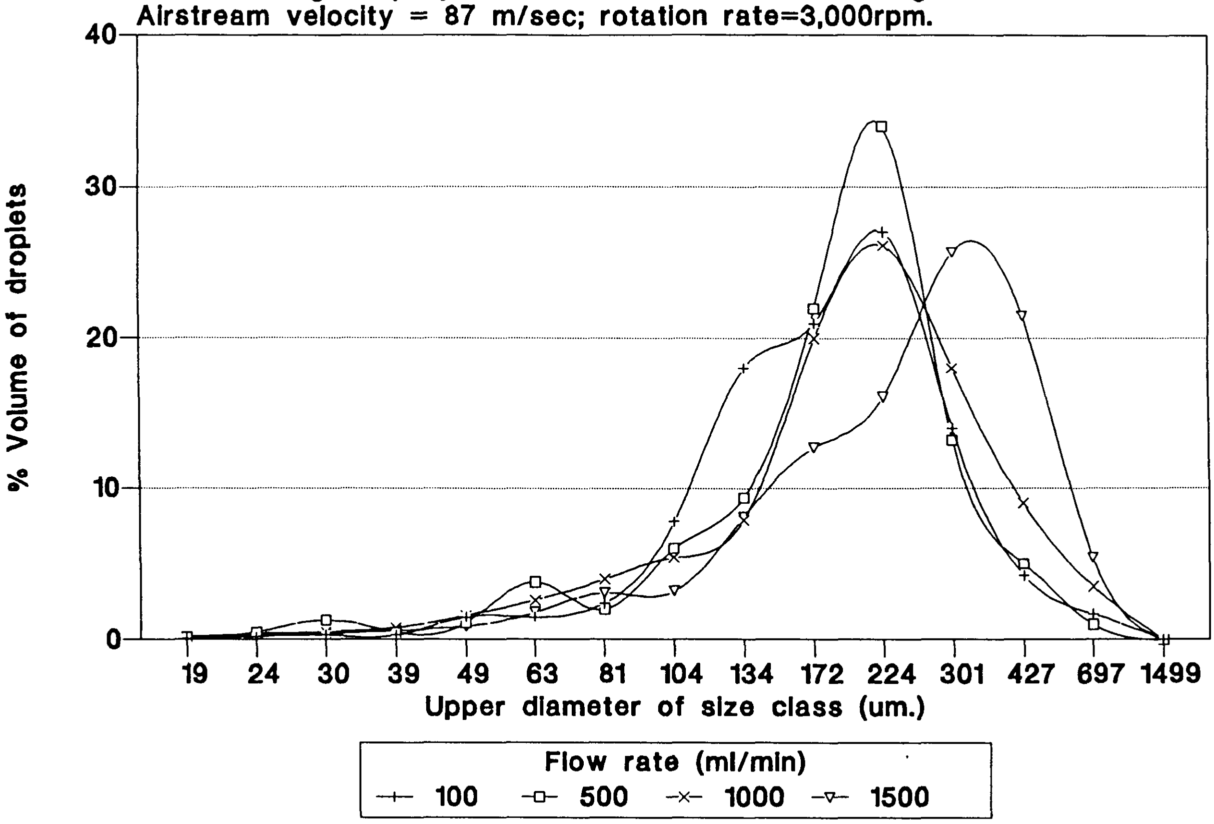


Fig 3.20 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 87 m/sec; rotation rate=3,000rpm.

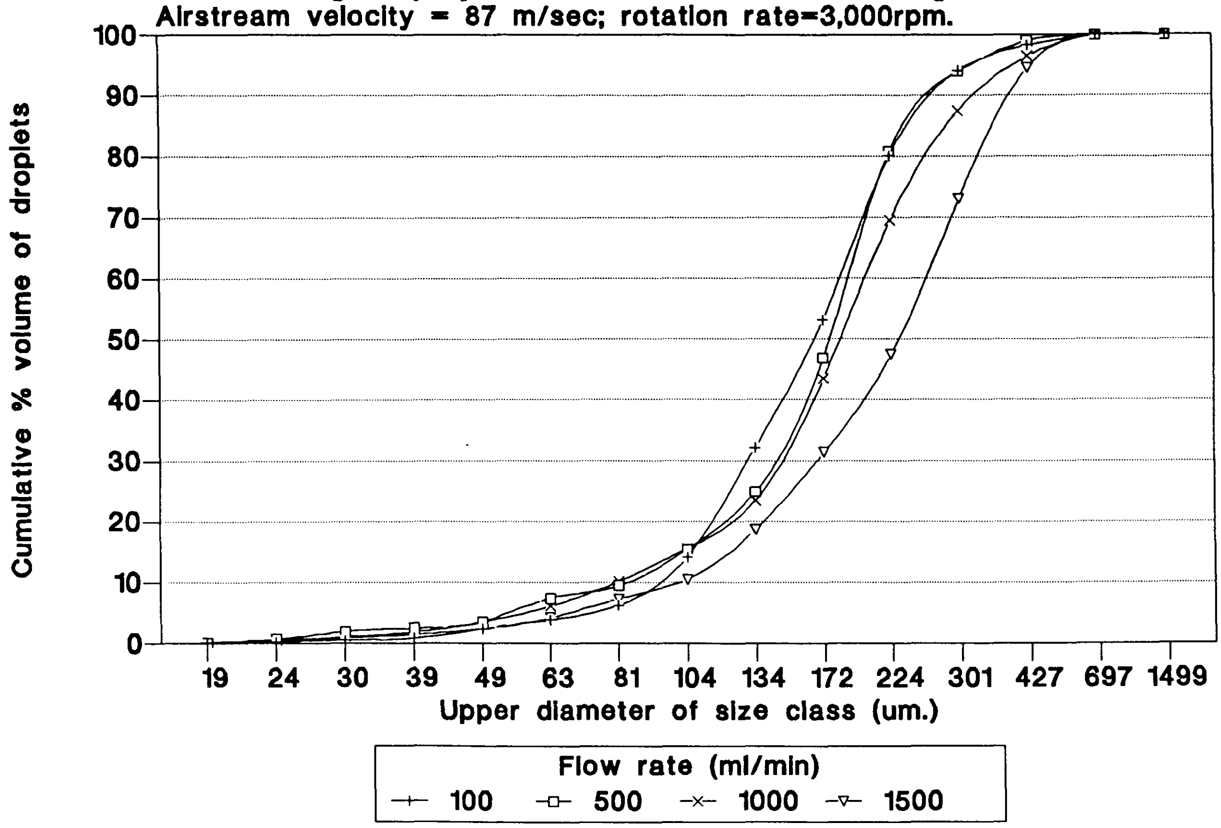


Fig 3.21 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 87 m/sec,rotation rate=11,000rpm.

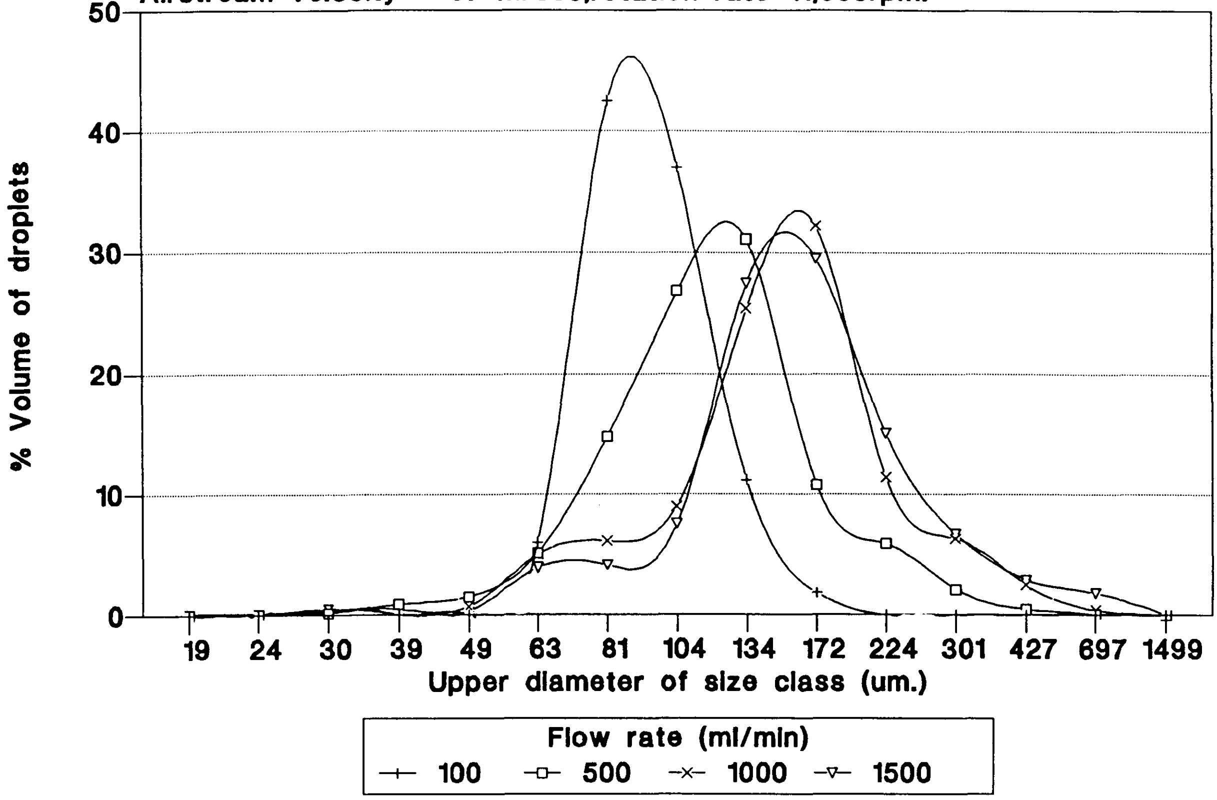


Fig 3.22 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 87 m/sec,rotation rate=11,000rpm.

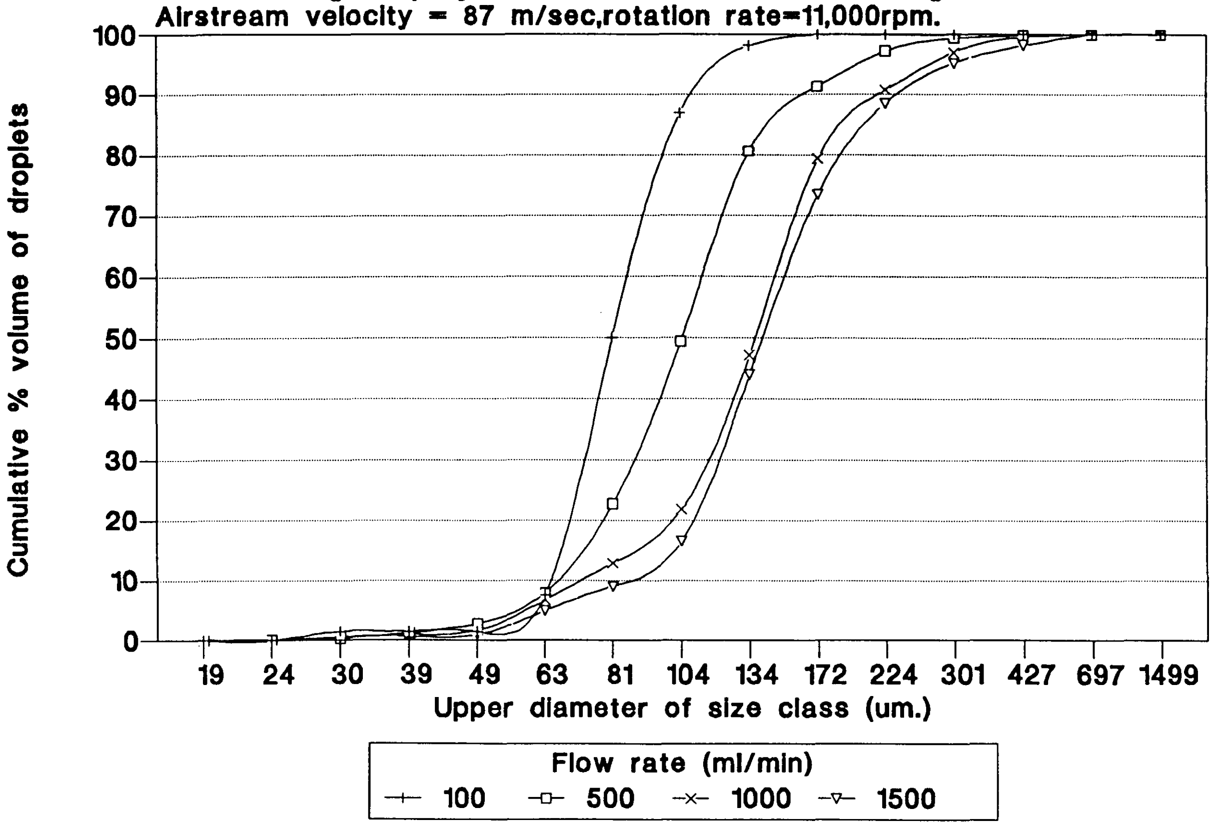


Fig 3.23 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity=87m/sec; Rotation rate=13,000rpm

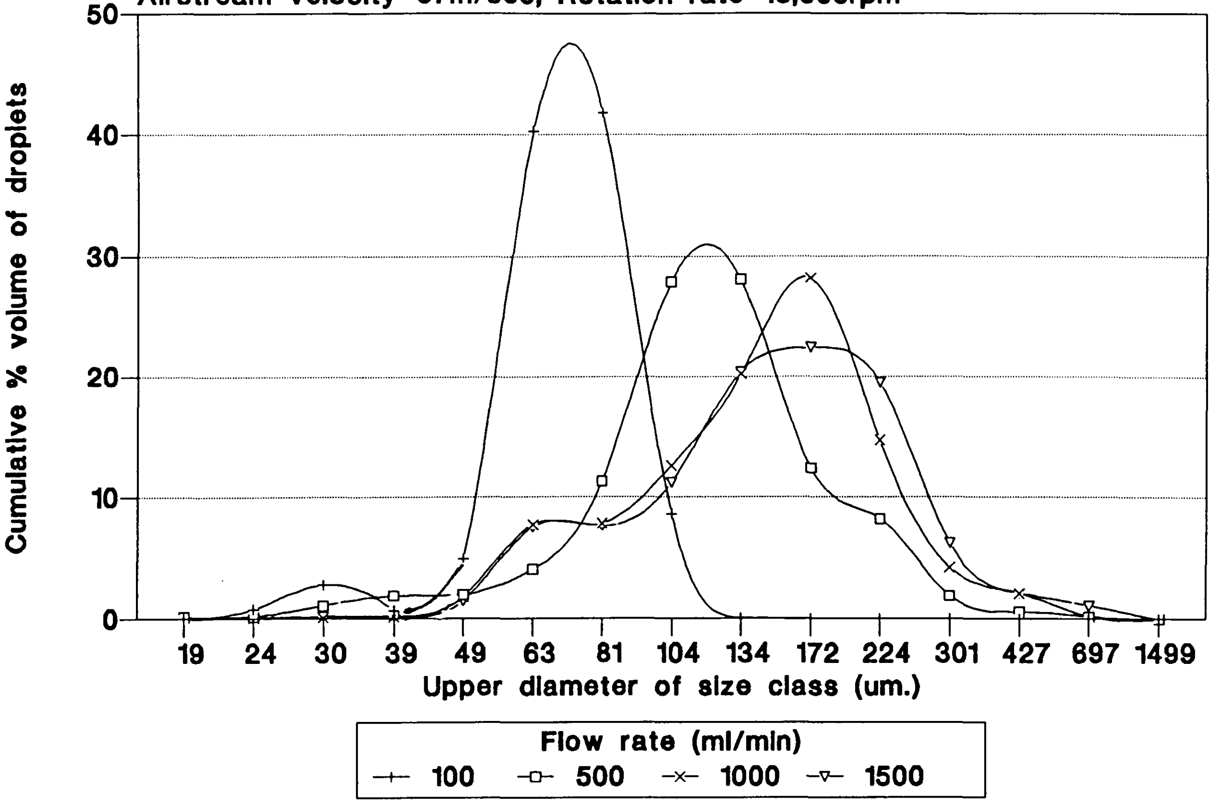


Fig 3.24 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity=87m/sec; Rotation rate=13,000rpm

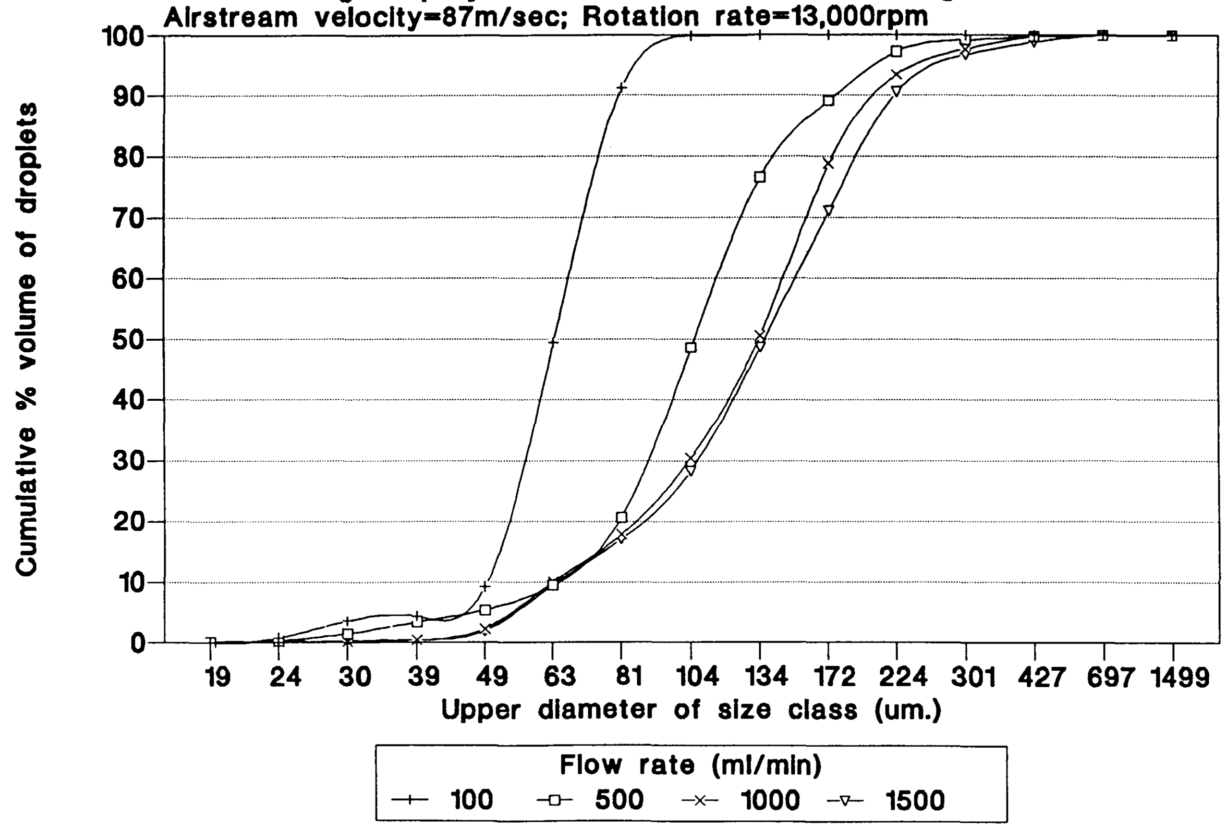


Fig 3.25 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec;rotation rate=6,000rpm.

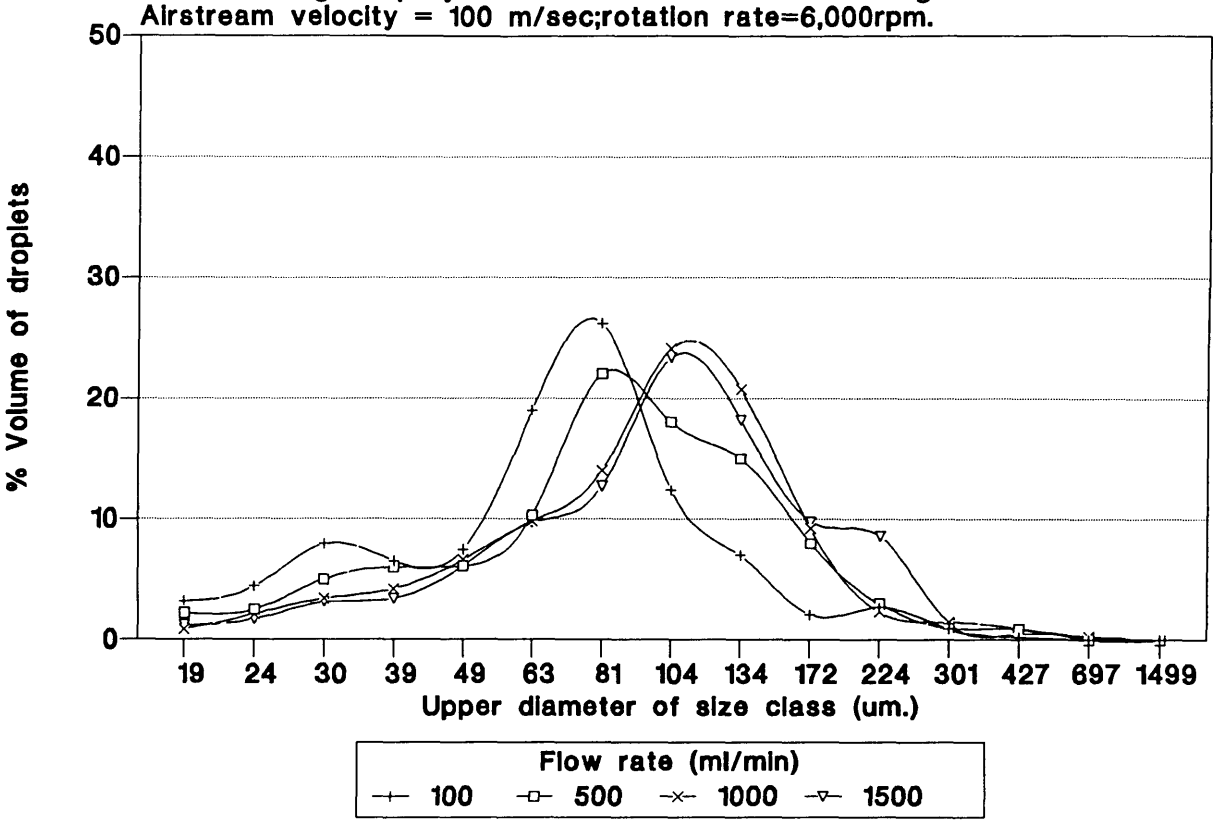


Fig 3.26 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec;rotation rate=6,000rpm.

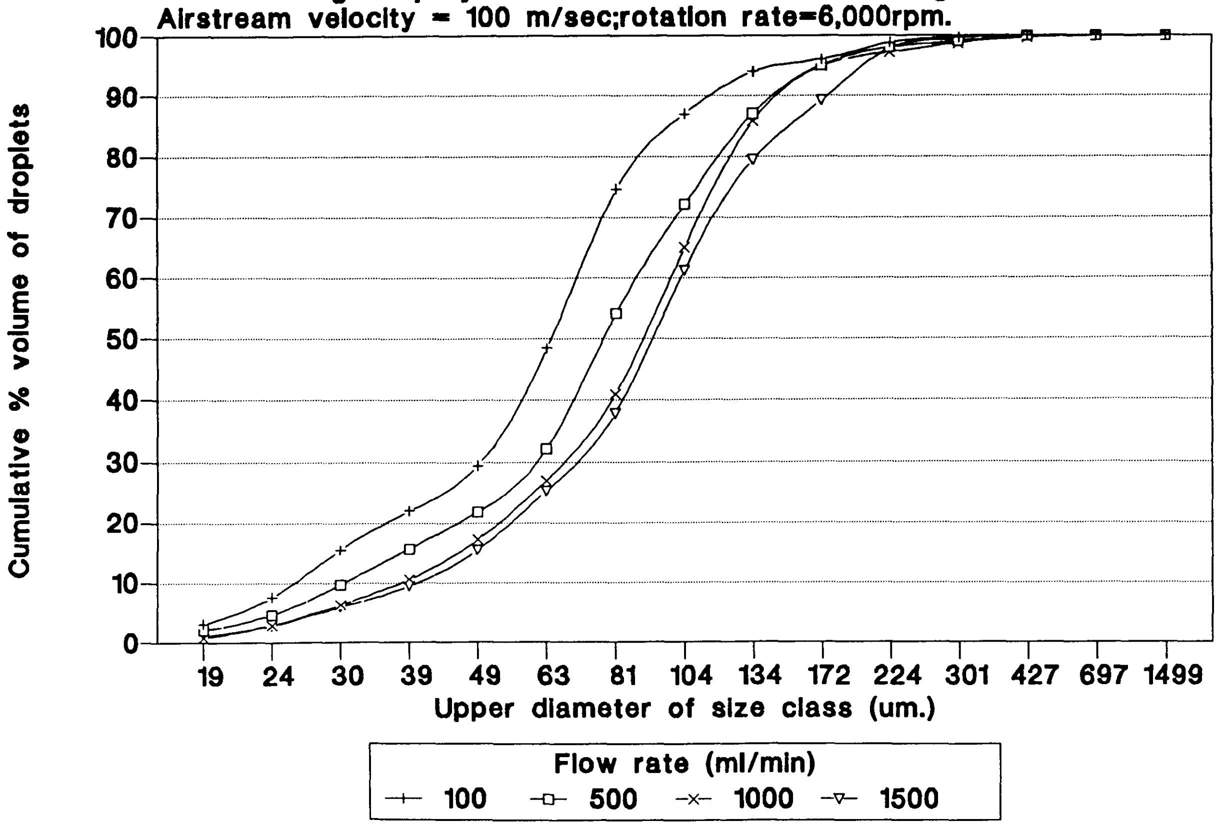


Fig 3.27 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec; rotation rate=11,000rpm.

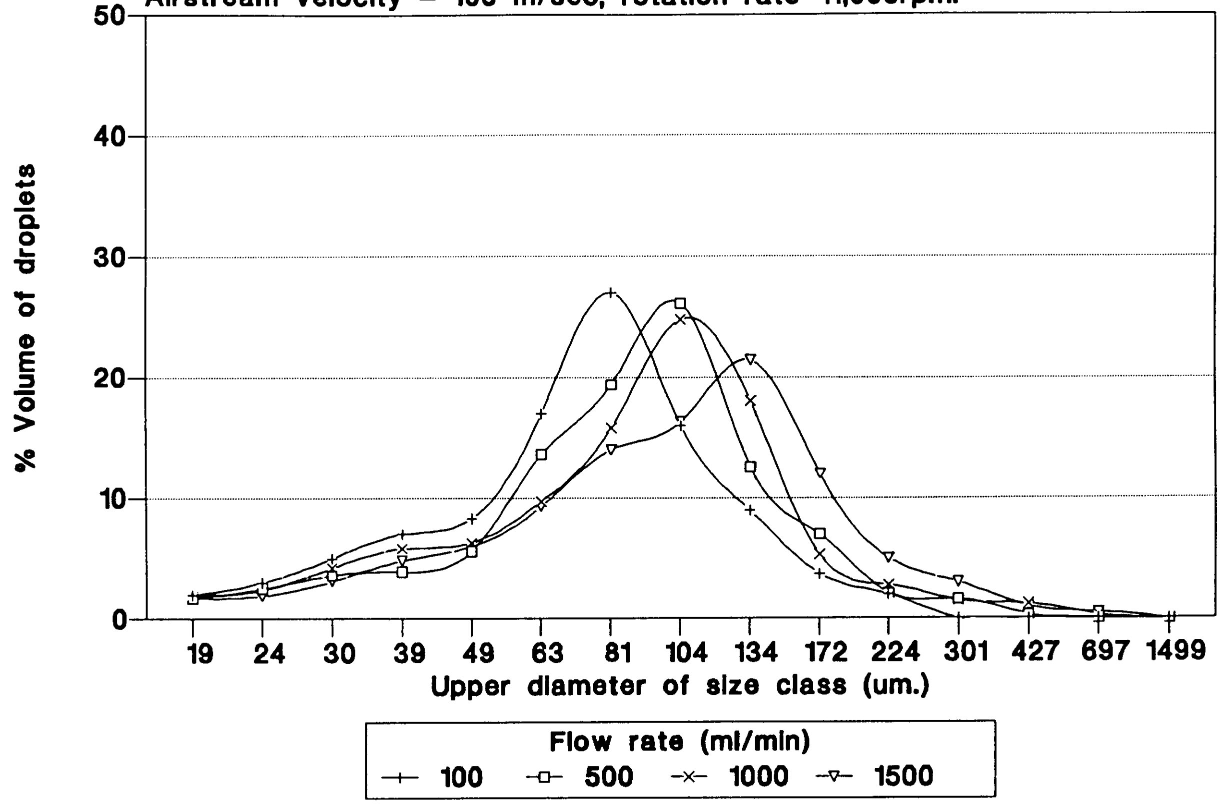


Fig 3.28 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec; rotation rate=11,000rpm.

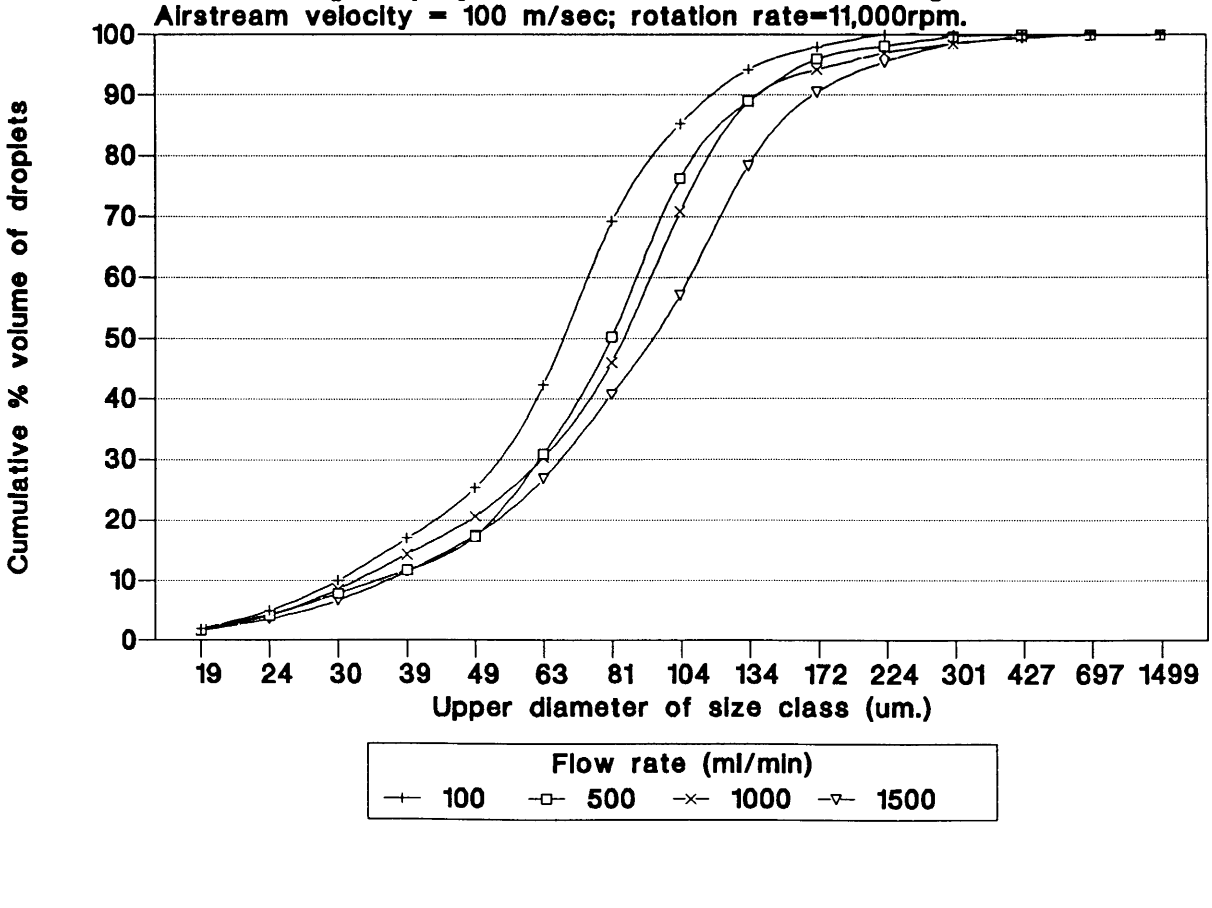


Fig3.29 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec,rotation rate=15,000rpm.

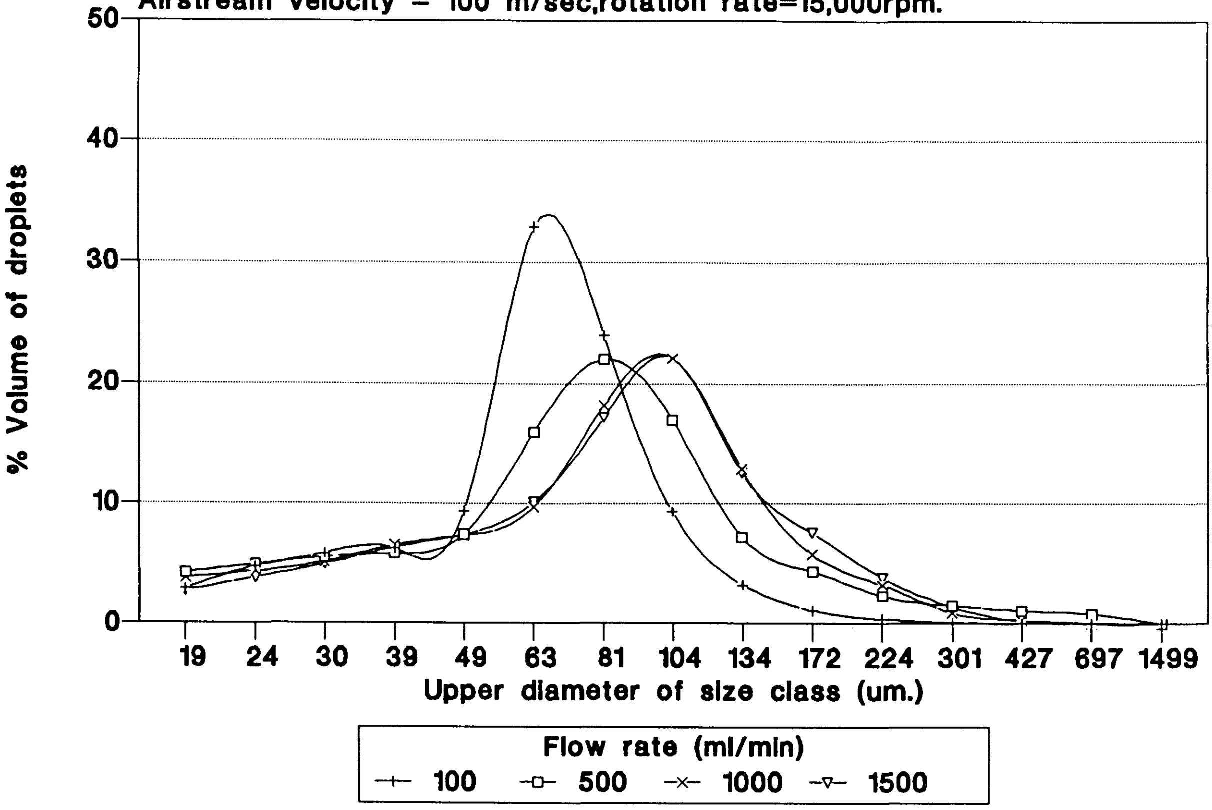


Fig3.30 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Airstream velocity = 100 m/sec,rotation rate=15,000rpm.

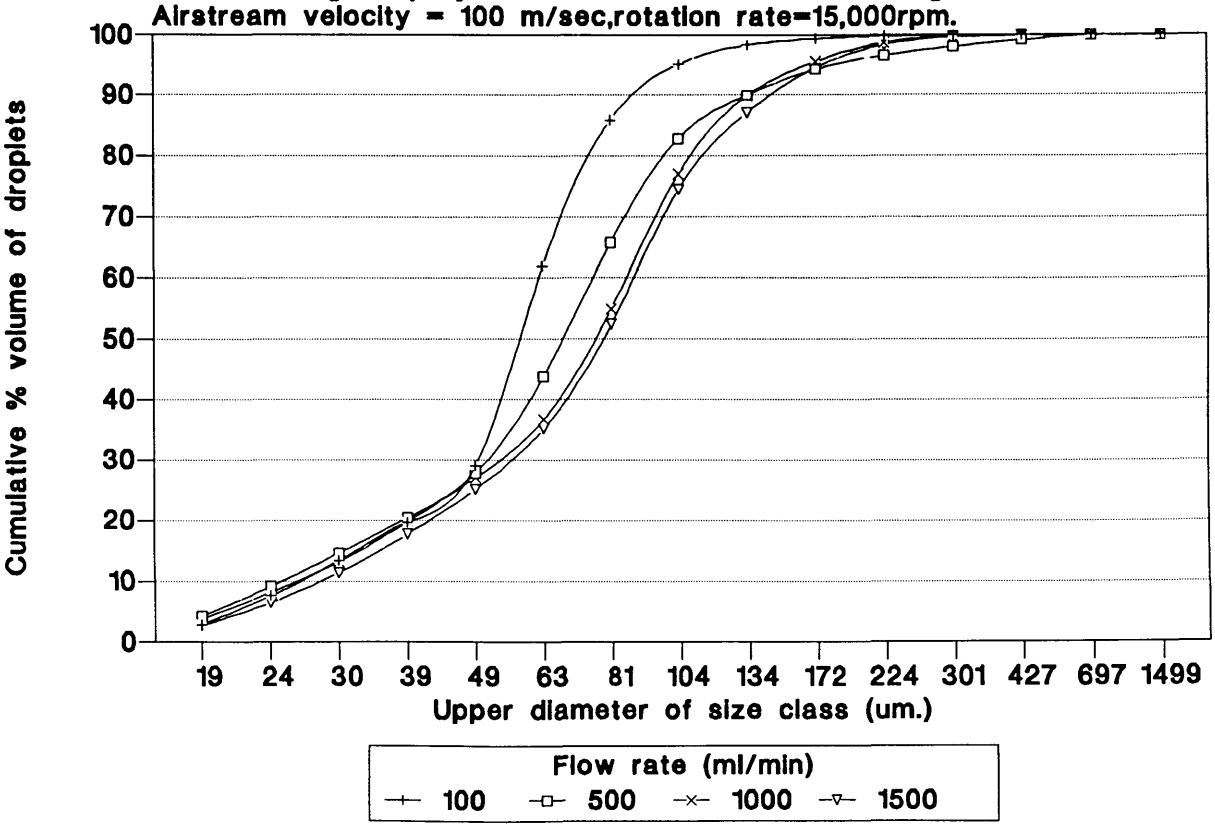


Fig 3.31 VMD against flow rate of water+Agral sprayed through non air-assisted X1 atomiser rotating at different rates.

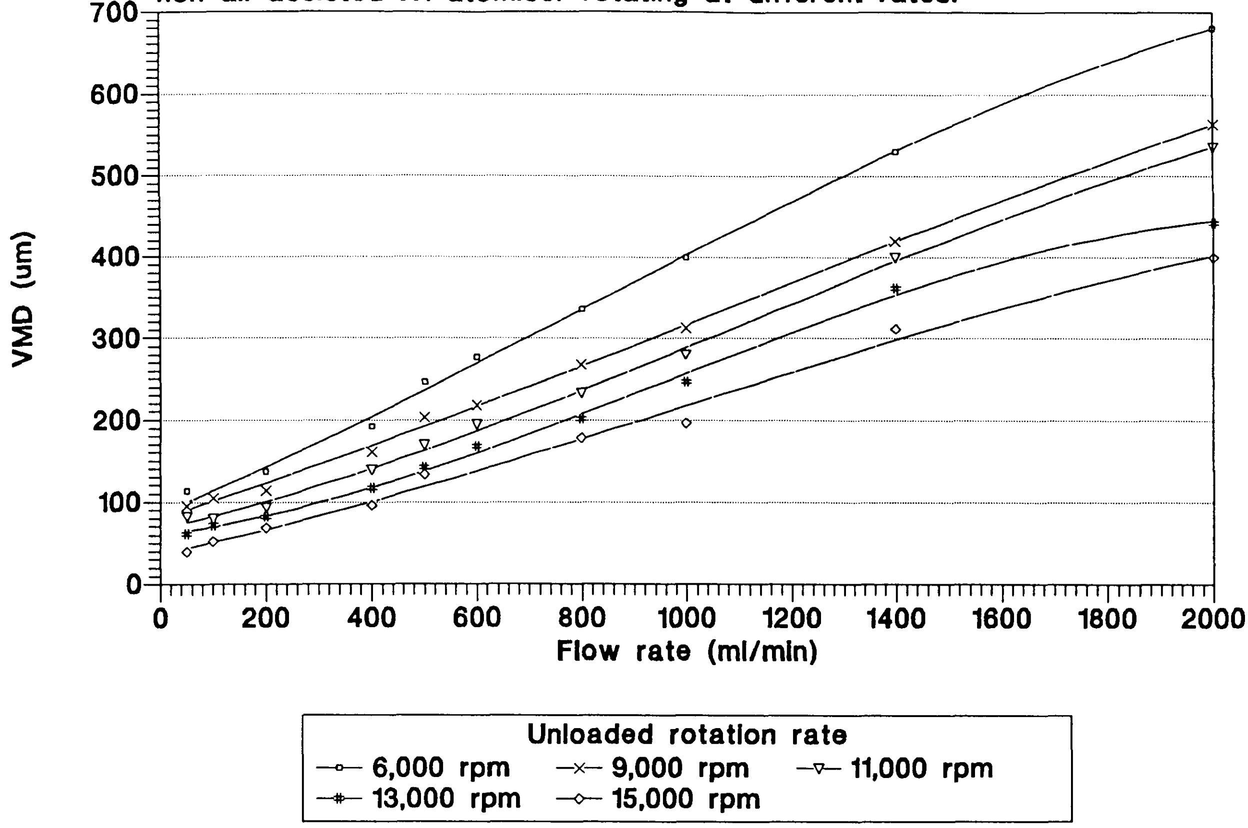
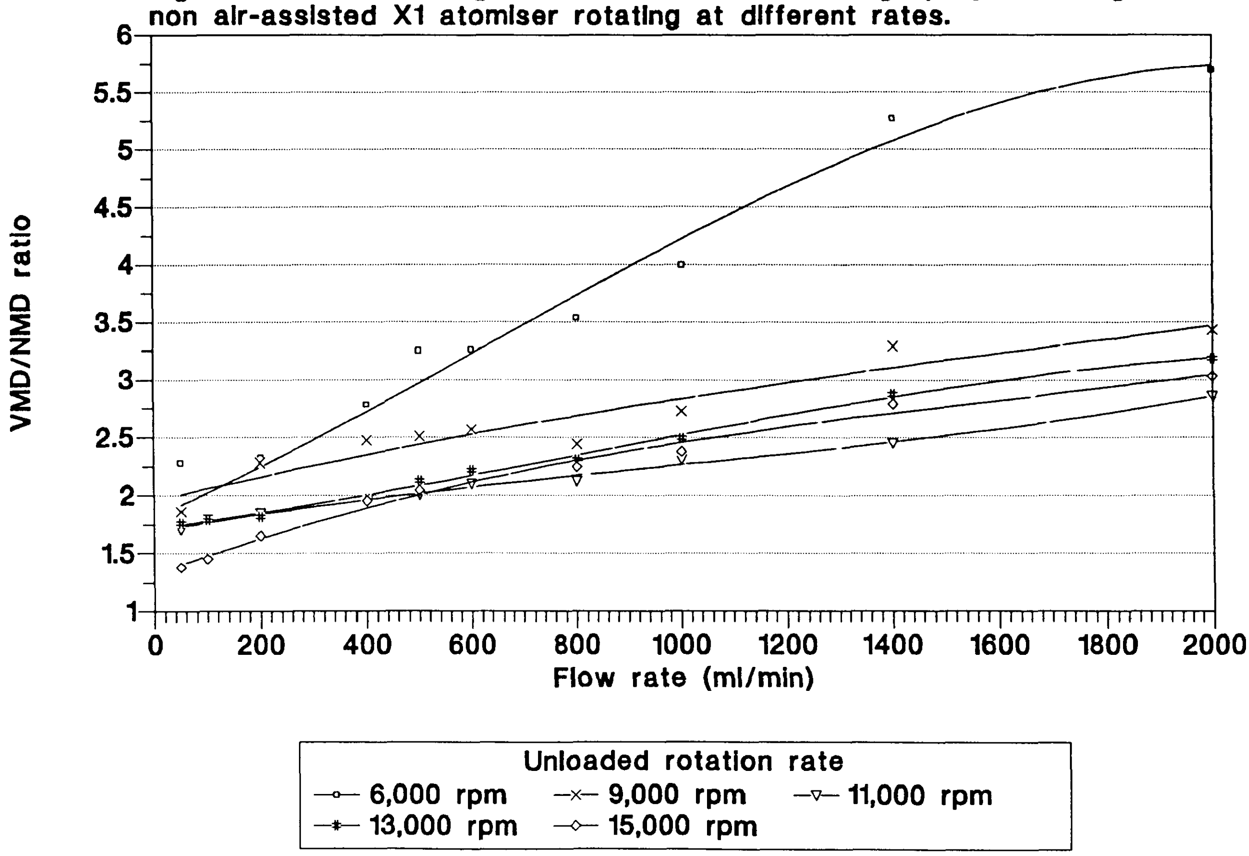


Fig 3.32 VMD/NMD ratio against flow rate of water+Ag sprayed through non air-assisted X1 atomiser rotating at different rates.



operated without air-assistance and in an airstream with a velocity of 87 m/sec.

The volumetric droplet size spectra produced by the non air-assisted X1 atomiser were generally bi-modal (Figs 3.33 to 3.38). As flow rate increased from 100 to 2000 ml/min, there was a clear shift in the volumetric droplet size spectra towards the larger droplets. Some of the droplets produced at a flow rate of 2000 ml/min and rotation rate of 6000 rpm probably had diameters above the upper size limit (1499 μm) of the 799 mm focal length lens used for these tests. The VMD derived under these conditions is therefore likely to be an underestimate of the actual VMD.

ROTARY CAGE ATOMISER

The VMD became larger as liquid flow rate increased (Fig 3.39). At a given flow rate, the VMD was largest for water+Agral and smallest for kerosene. The VMD/NMD ratios also increased with increasing liquid flow rate (Fig 3.40). Kerosene produced the lowest VMD/NMD ratios. The rates of changes in the VMD and the VMD/NMD ratio were low, with a difference of only 5 to 9 μm between the VMD at 150 ml/min and 2000 ml/min, and only 0.3 to 0.5 between the VMD/NMD ratios at these flow rates.

There were large differences in the VMD and VMD/NMD ratios produced by all liquids at different airstream velocities

Fig 3.33 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 6,000 rpm

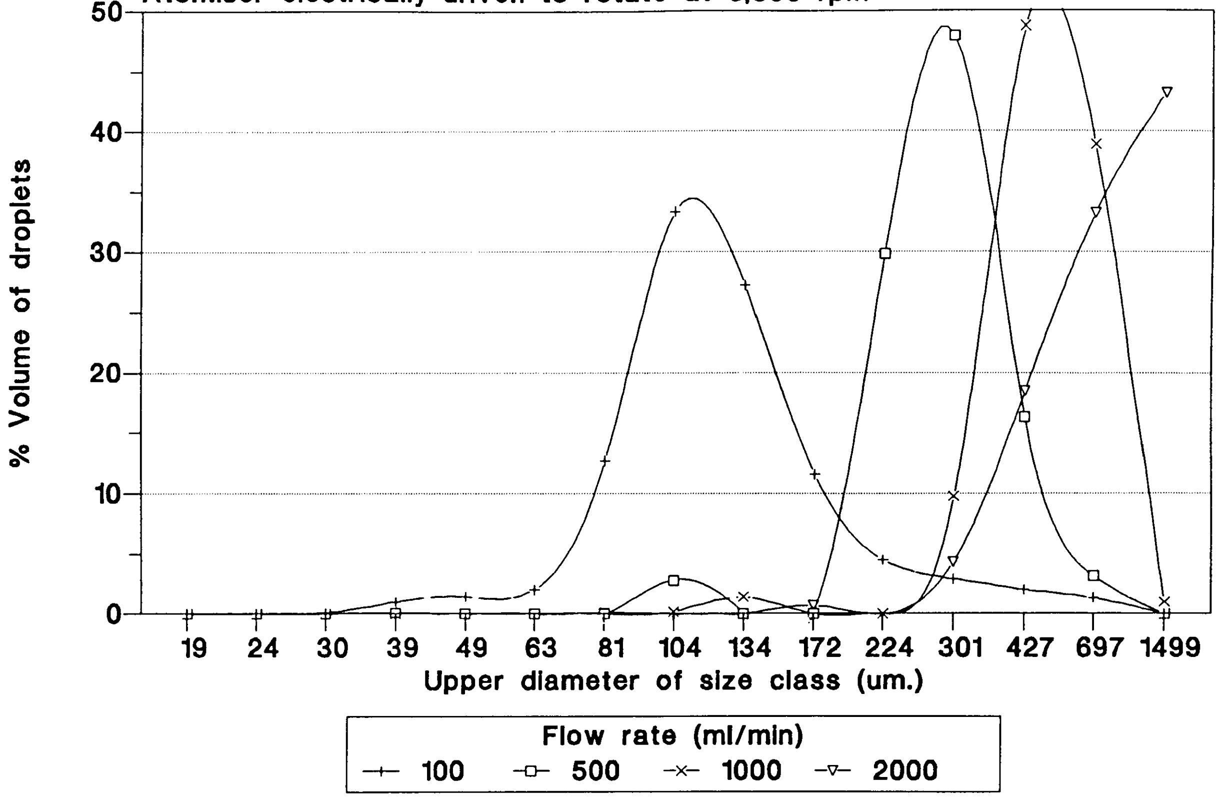


Fig 3.34 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 6,000 rpm

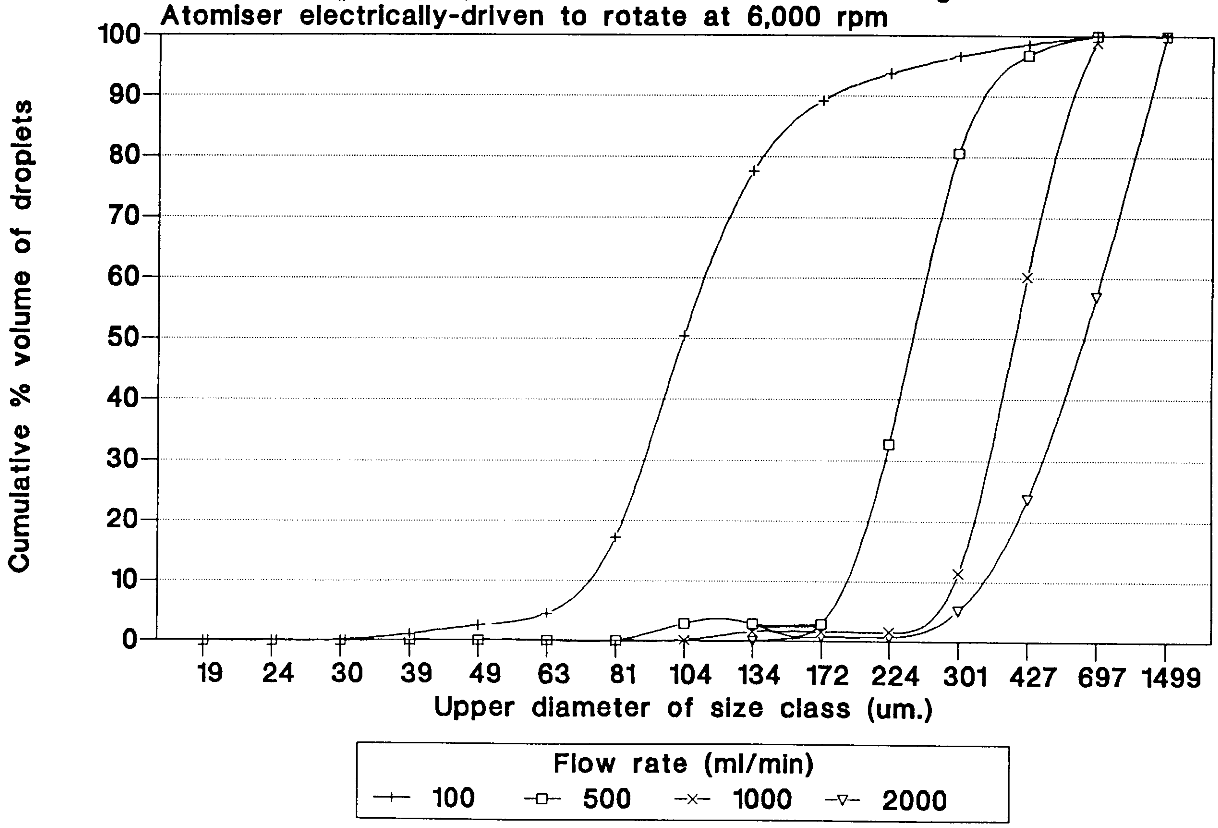


Fig 3.35 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 11,000 rpm

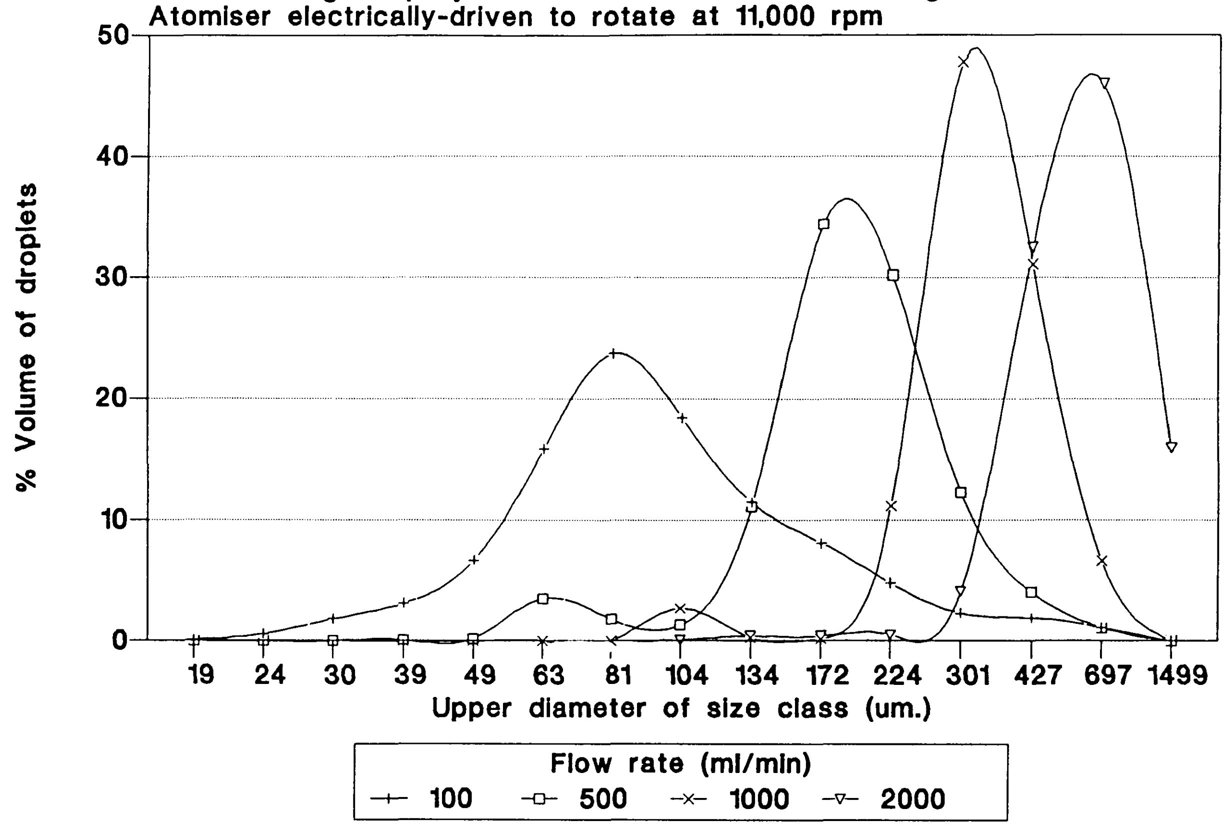


Fig 3.36 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 11,000 rpm

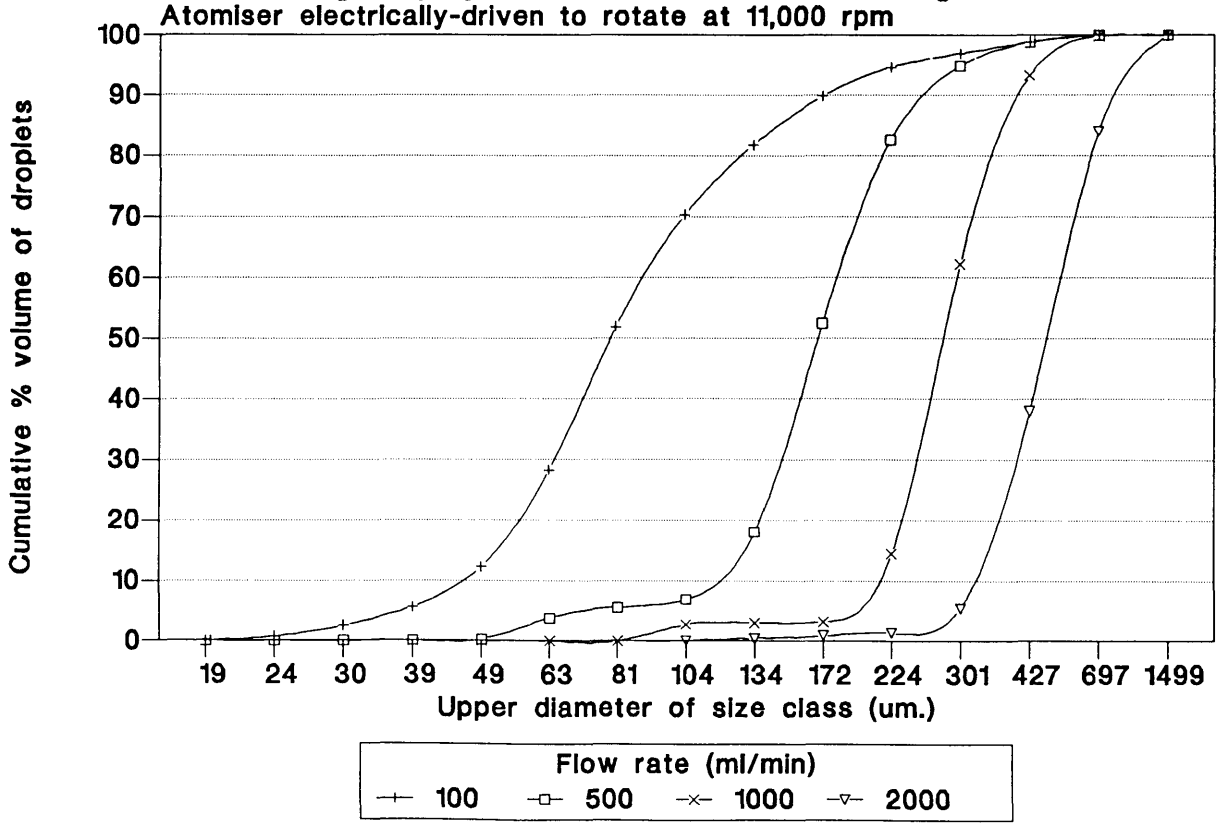


Fig 3.37 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 15,000 rpm

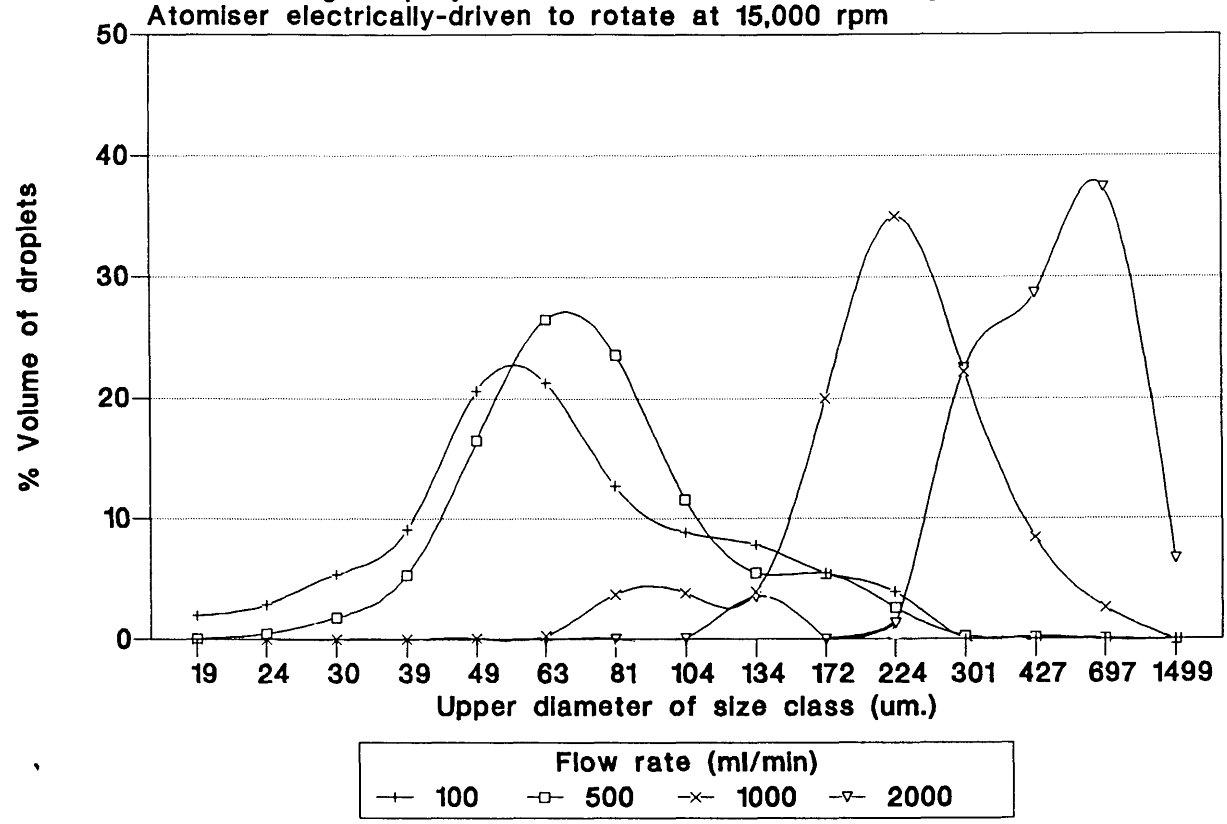


Fig 3.38 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through X1 atomiser. Atomiser electrically-driven to rotate at 15,000 rpm

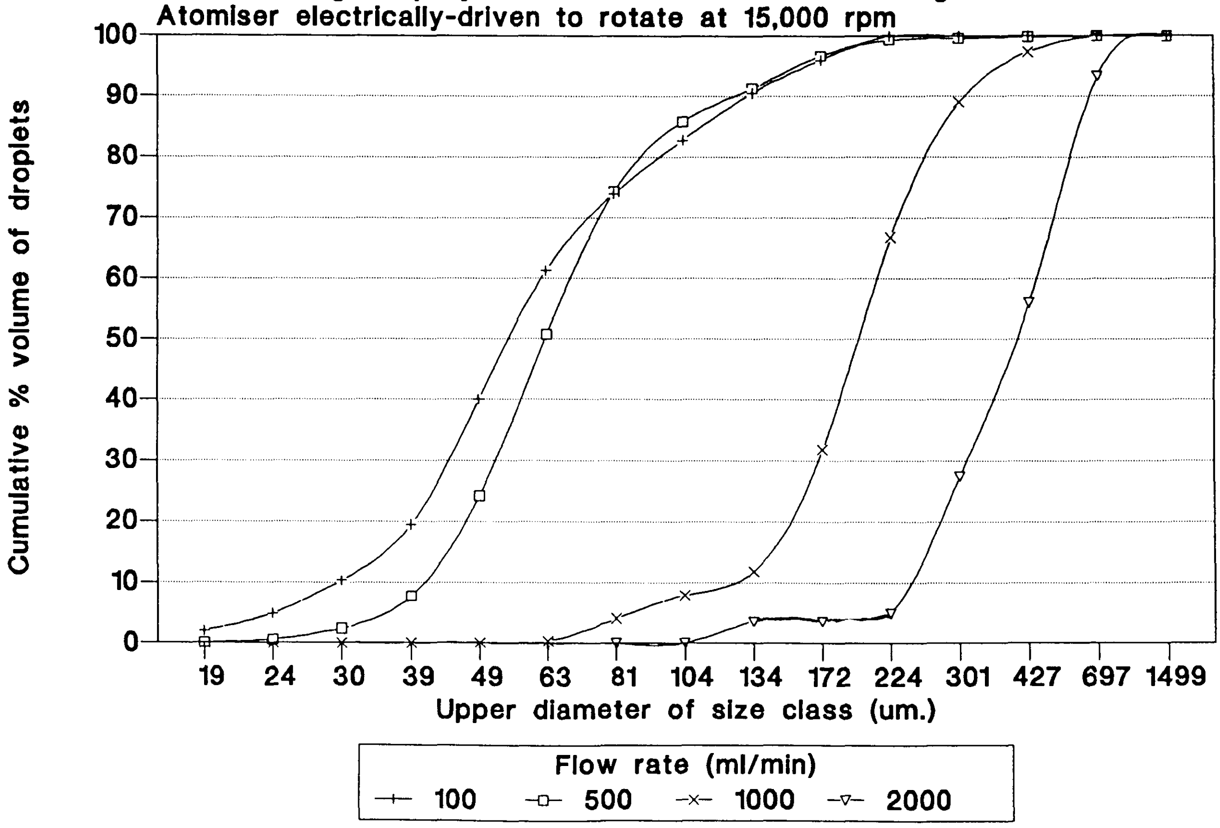


Fig 3.39 VMD against flow rate for water+Agral, kerosene and Risella atomised by an AU8000 in a 116 m/sec airstream.

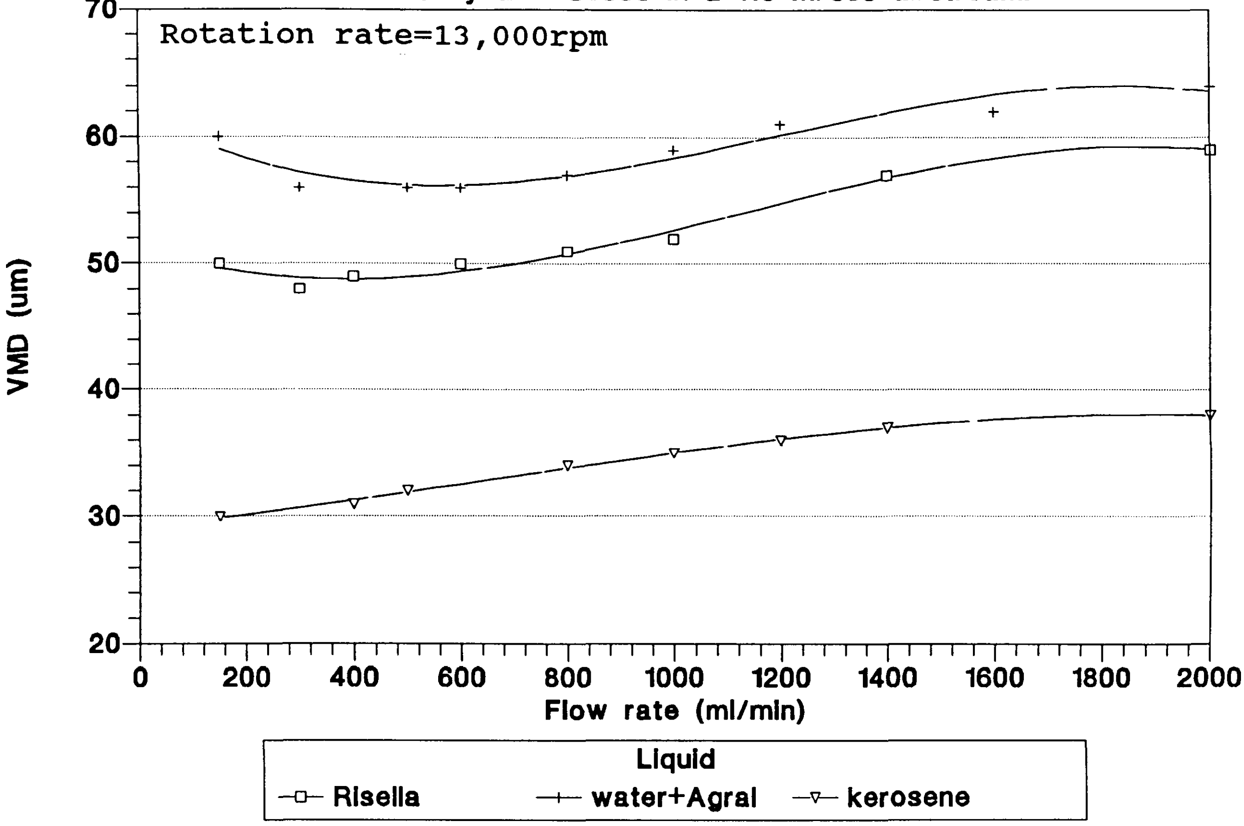
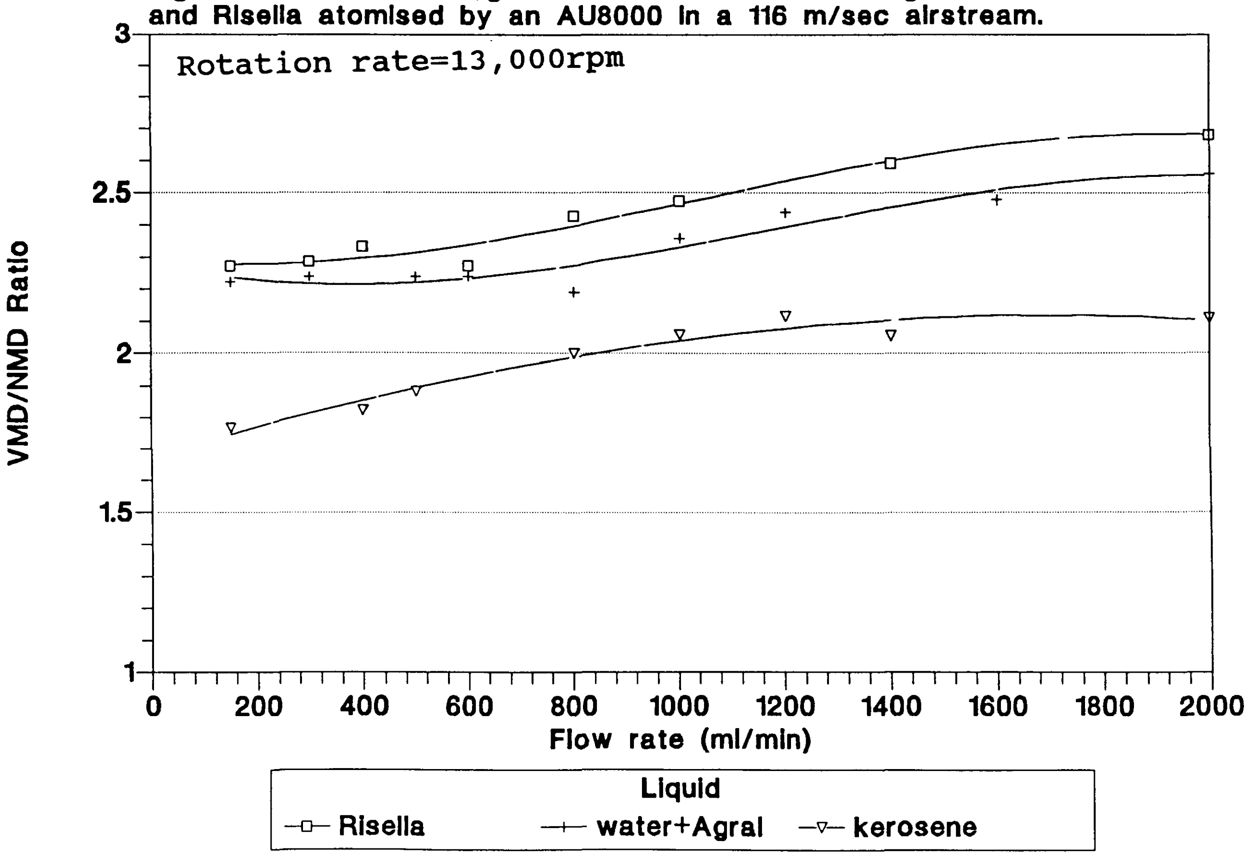


Fig 3.40 VMD/NMD ratio against flow rate for water+Ag, kerosene and Risella atomised by an AU8000 in a 116 m/sec airstream.



and rotation rates (Figs 3.41 to 3.46). The VMD increased as the airstream velocity and/or the rotation rate decreased. At an airstream velocity of 116 m/sec, the VMD/NMD ratio decreased with increasing rotation rate for each liquid. At 87 m/sec airstream velocity, a similar effect occurred except for water+Agral which produced an increase in VMD/NMD ratio as rotation rate increased from 100 to 1500 rpm, and decreased at higher rotation rates.

The droplet size spectra for water+Agral were bi-modal at 100 ml/min flow rate and tri-modal at higher flow rates (Figs 3.47 and 3.48). Kerosene produced tri-modal spectra at all flow rates (Figs 3.49 and 3.50). The spectra produced by Risella were bi-modal at flow rates up to 1500 ml/min, and tri-modal at 2000 ml/min flow rate (Figs 3.51 and 3.52).

SLOTTED ROTARY DRUMS

The increase in the VMD and VMD/NMD ratio with a higher flow rate was greater at the lowest rotational speed (Figs 3.53 and 3.54). The VMD was smaller with the addition of an external 30 m/sec airstream.

The VMD/NMD ratio was less than 2 when flow rate was below 600 ml/min, rising to 2.9 to 4.3 at a flow rate of 1800 ml/min (Fig 3.54). The VMD/NMD ratio tended to fall with higher rotation rate.

Fig. 3.41 VMD against rotation rate of AU8000 at different airstream velocities for water+Agral with a flow rate of 800ml/min.

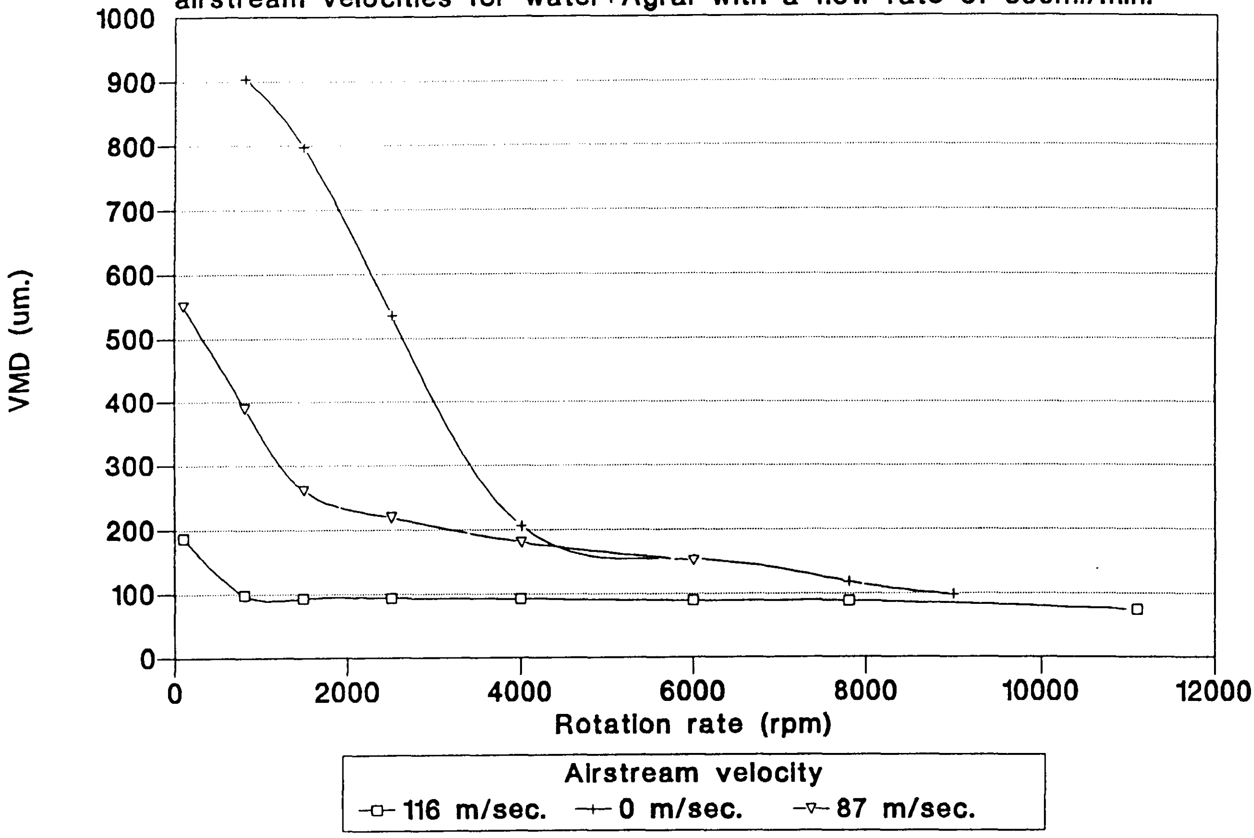


Fig 3.42 VMD/NMD ratio against rotation rate of AU8000 at different airstream velocities for water+Agral at 800 ml/min flow rate.

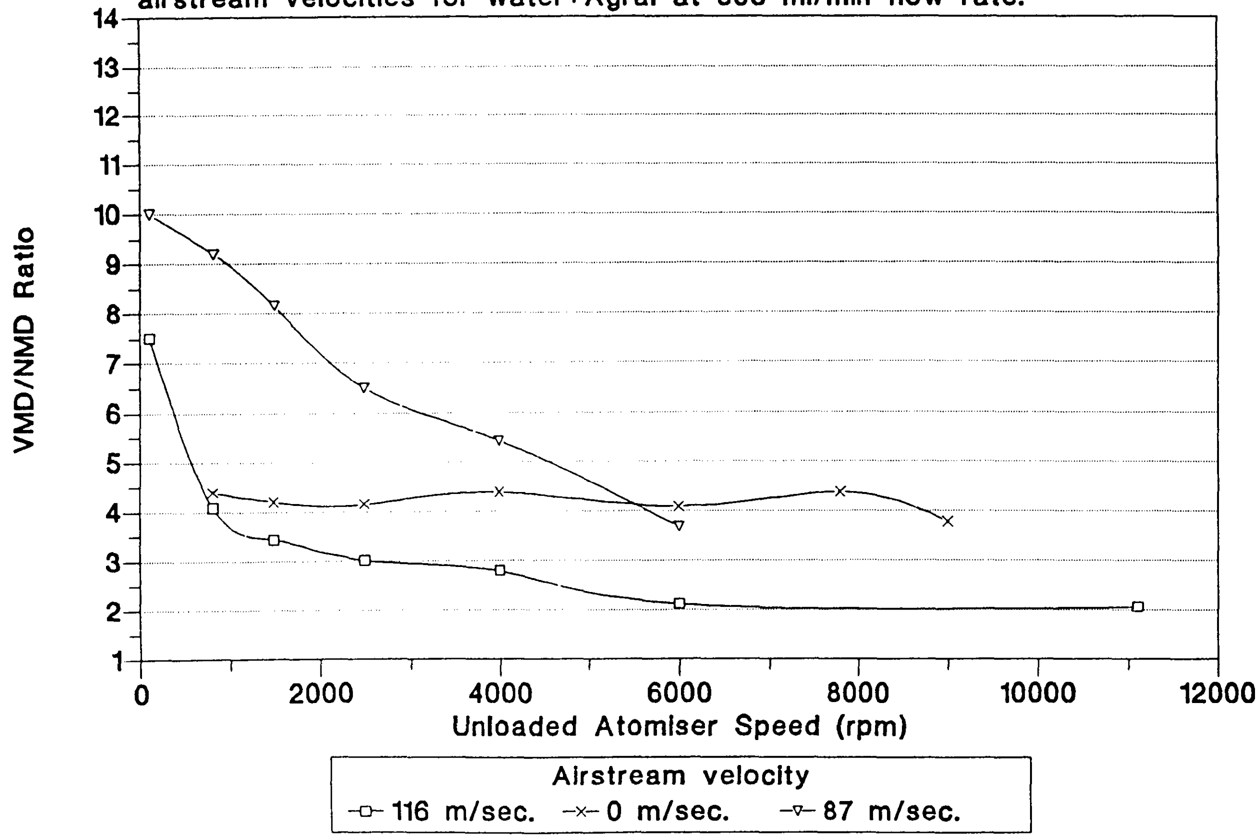


Fig. 3.43 VMD against rotation rate of AU8000 at different airstream velocities for kerosene with a flow rate of 800ml/min.

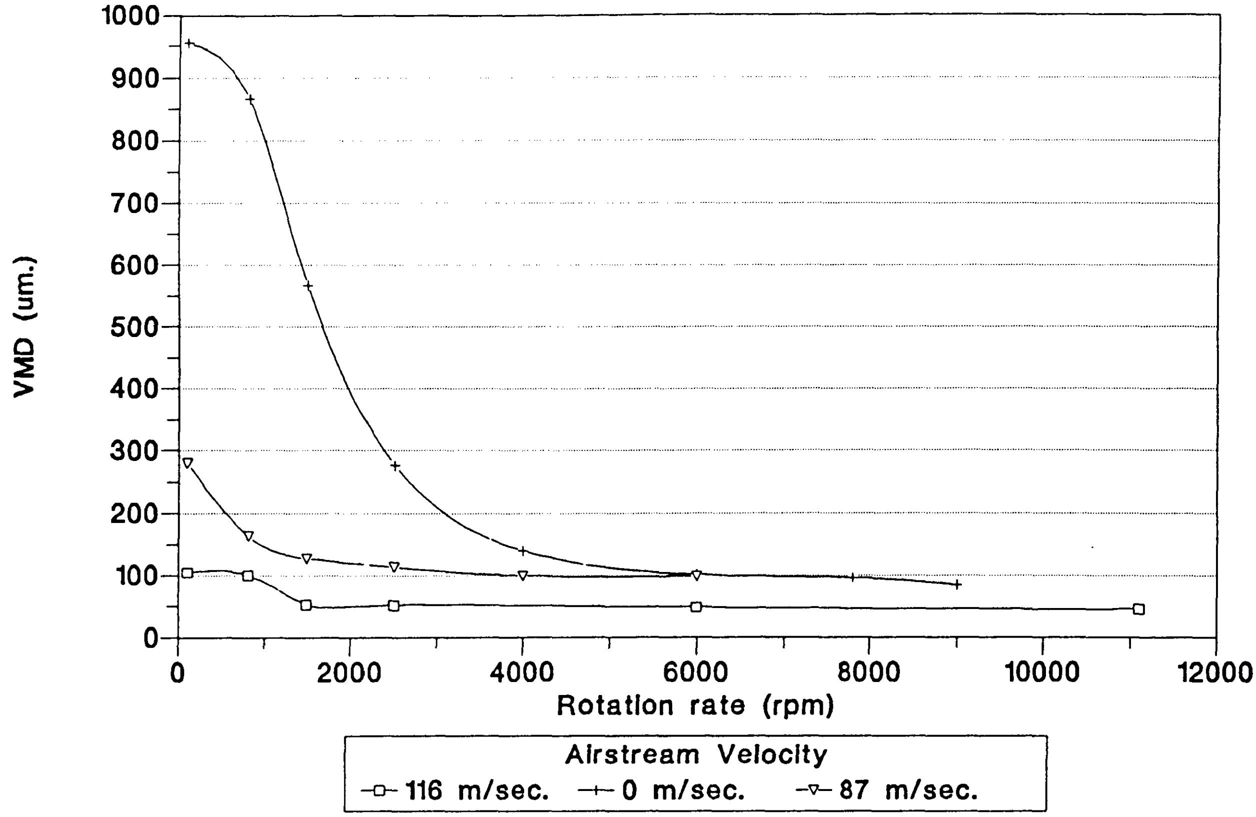


Fig. 3.44 VMD/NMD ratio against rotation rate of AU8000 at different airstream velocities for kerosene with a flow rate of 800ml/min.

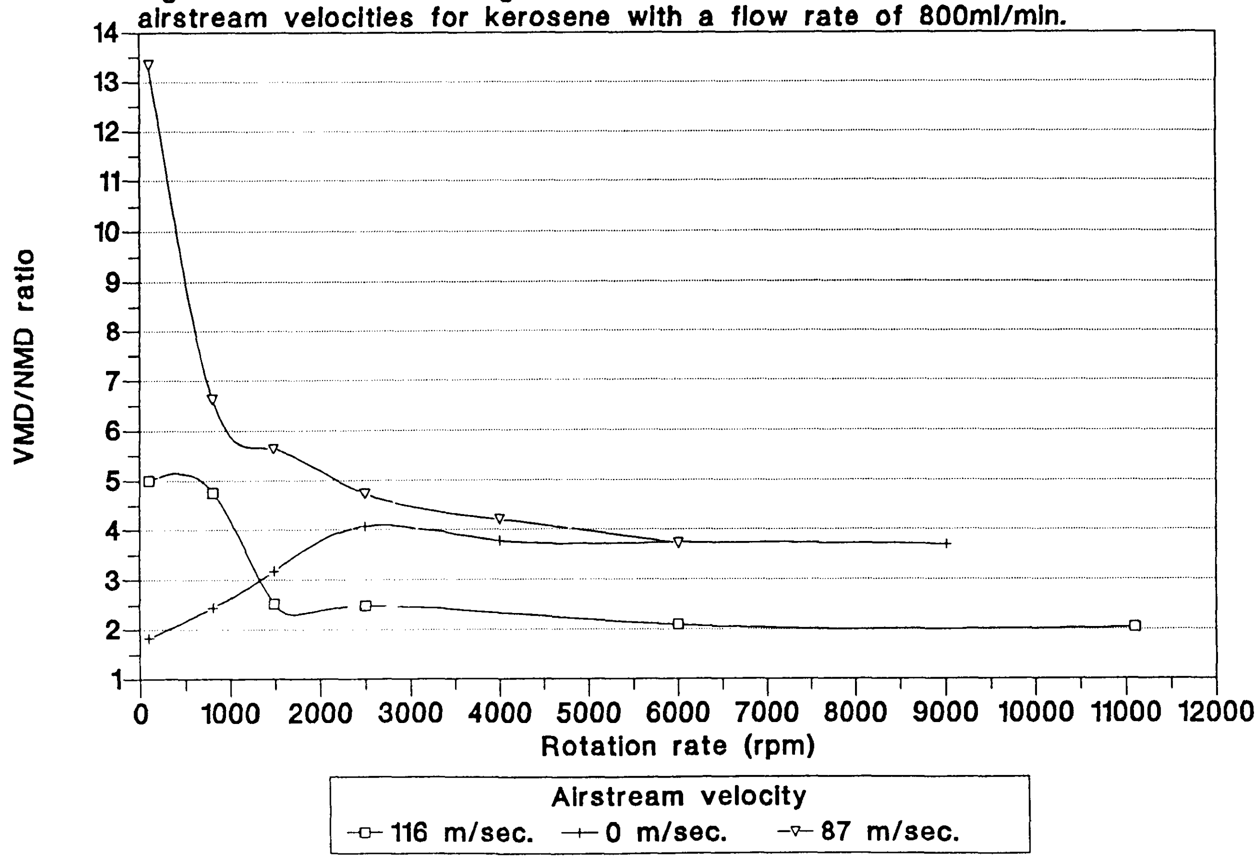


Fig.3.45 VMD against rotation rate of AU8000 at different airstream velocities for Risella with a flow rate of 800ml/min.

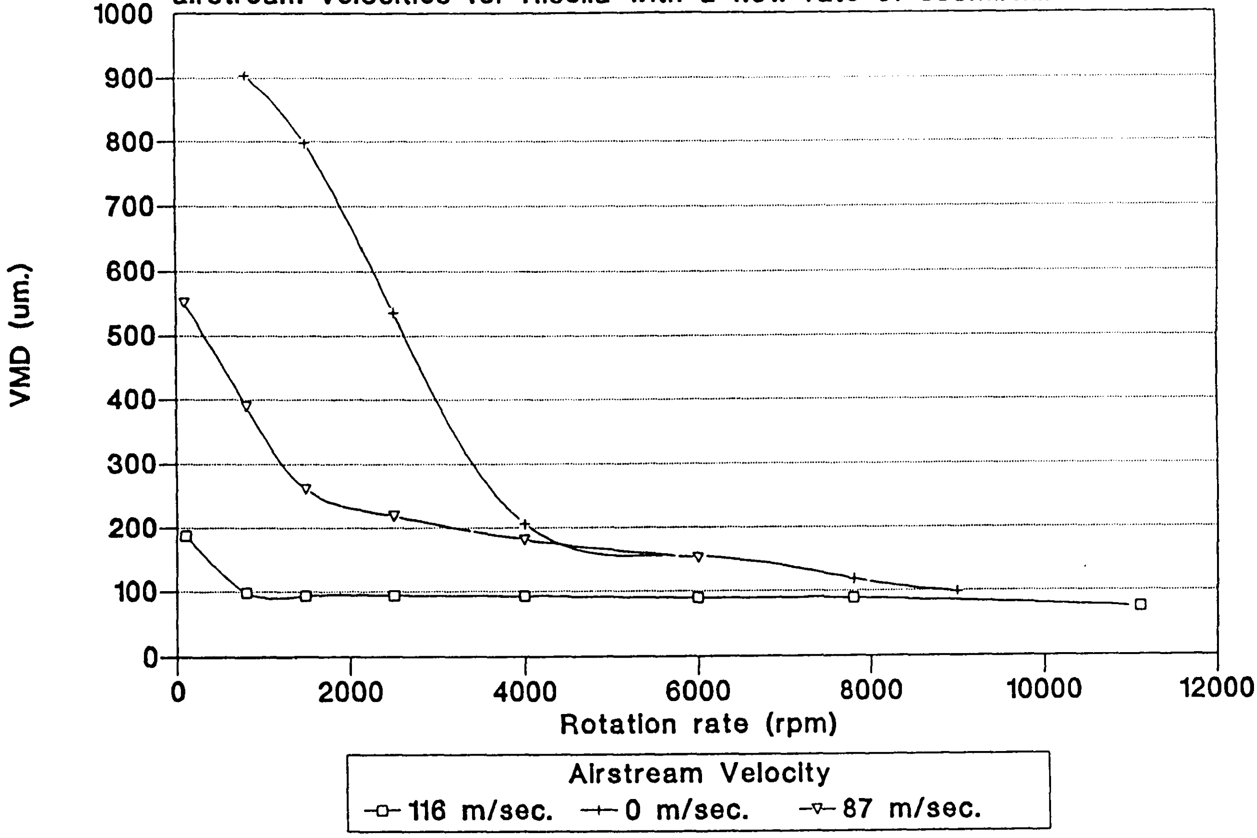


Fig3.46VMD/NMD ratio against rotation rate of AU8000 at different airstream velocities for Risella at 800 ml/min flow rate.

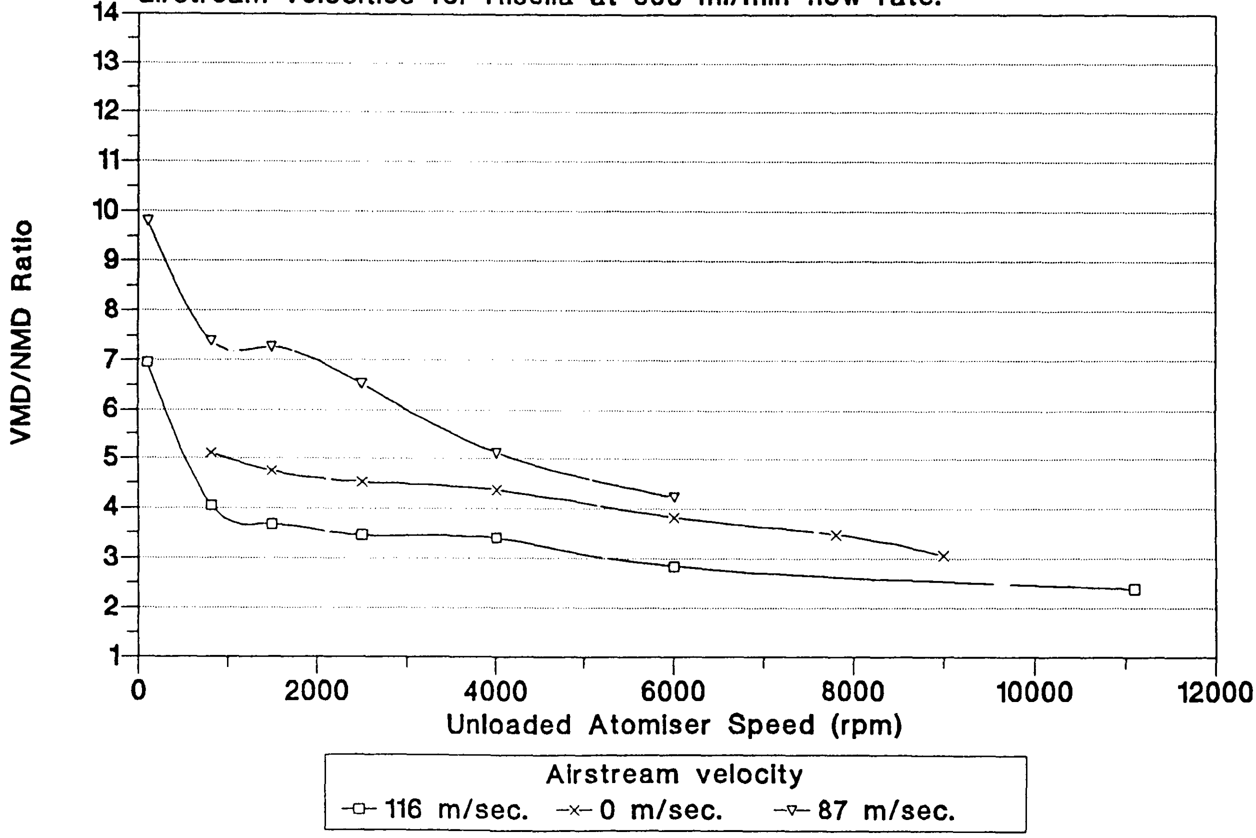


Fig 3.47 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

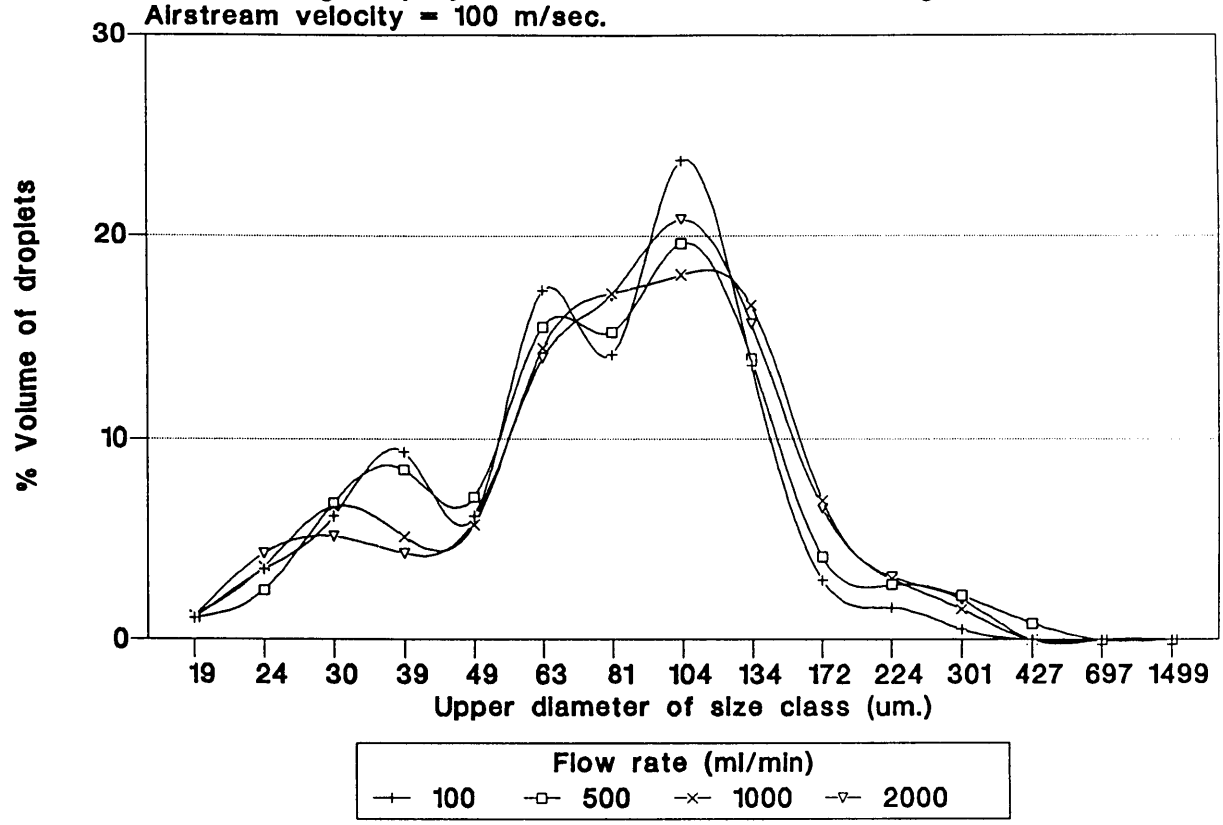


Fig 3.48 Cumulative percentage vol. droplet distributions among size classes for water+Agral sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

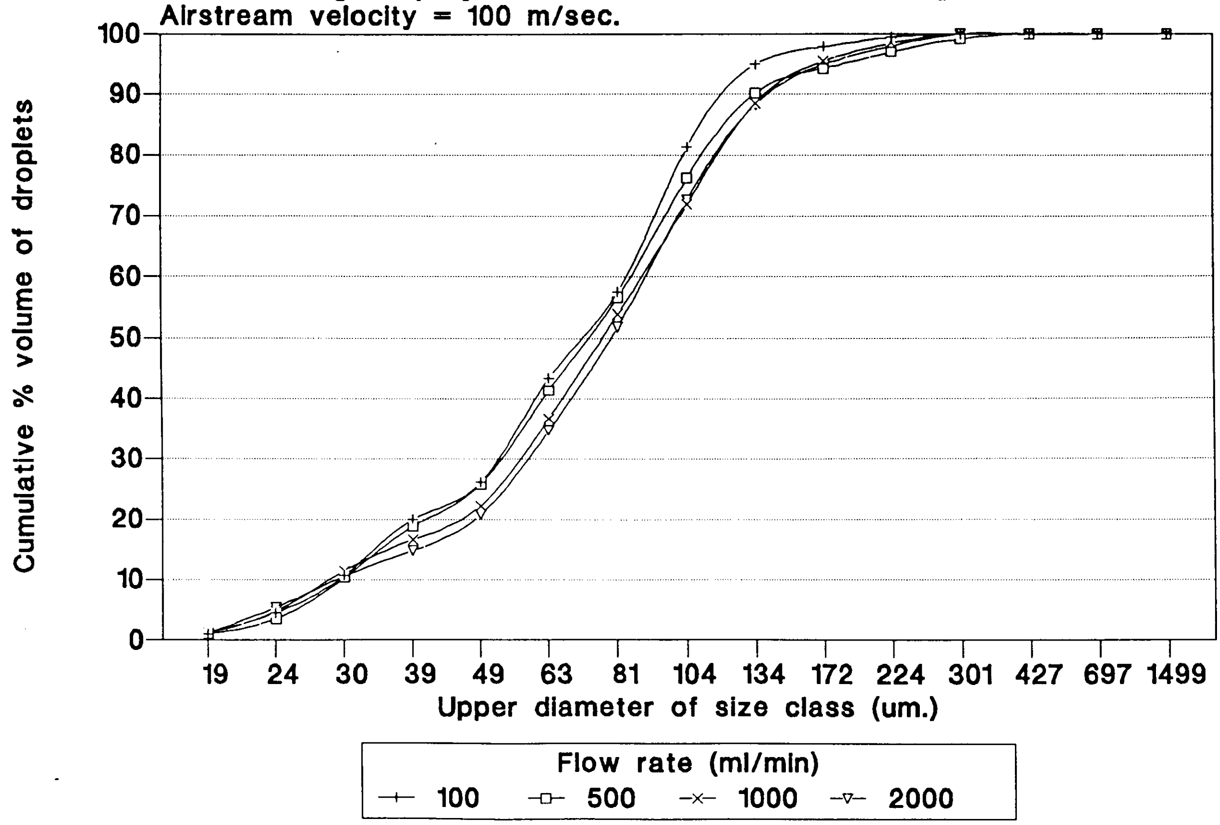


Fig 3.49 Percentage volume droplet distributions among size classes for kerosene sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

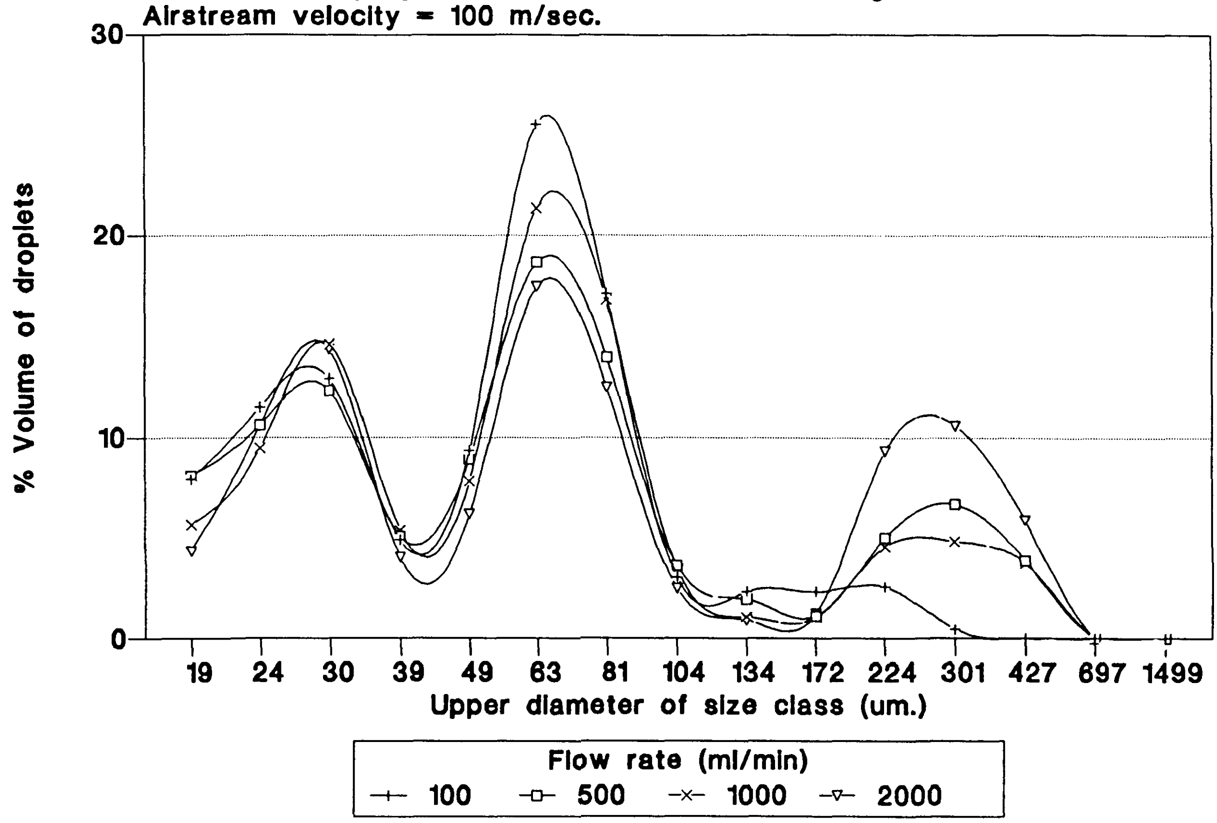


Fig 3.50 Cumulative percentage vol. droplet distributions among size classes for kerosene sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

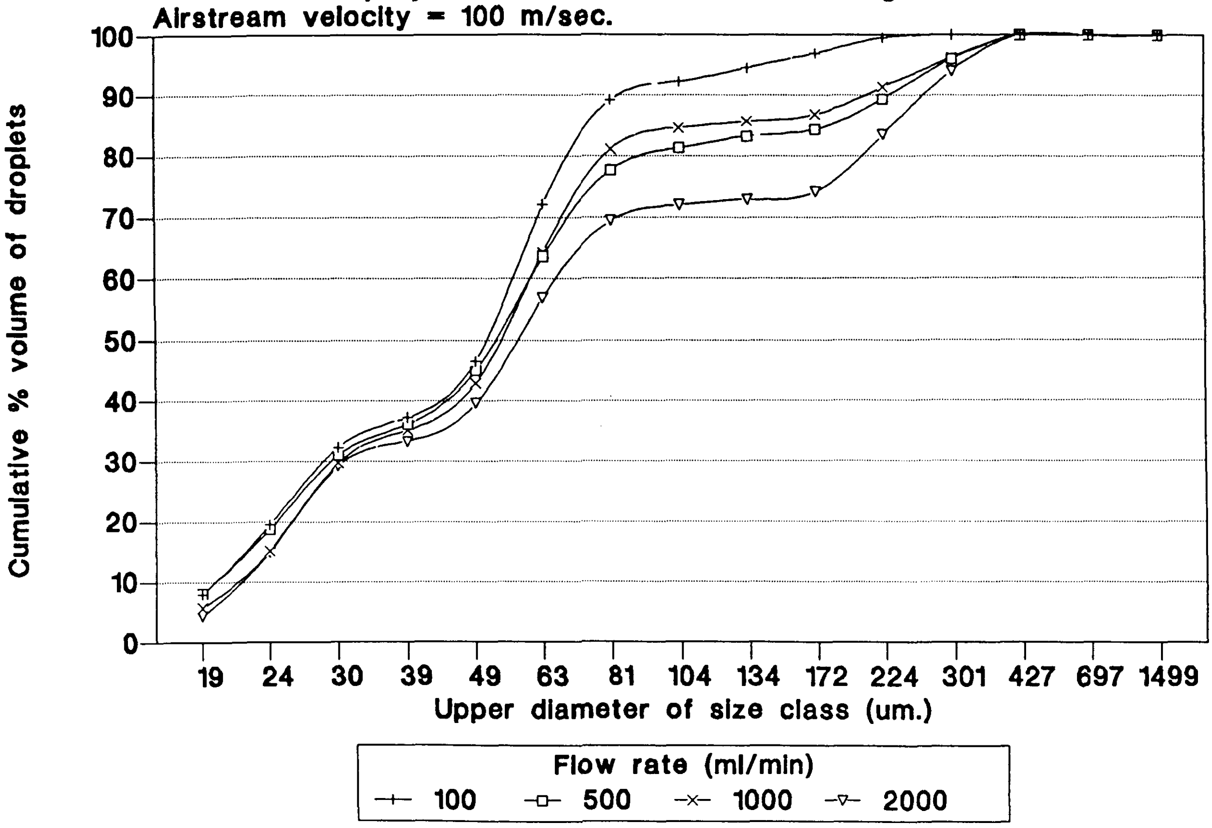


Fig3.51 Percentage volume droplet distributions among size classes for Risella sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

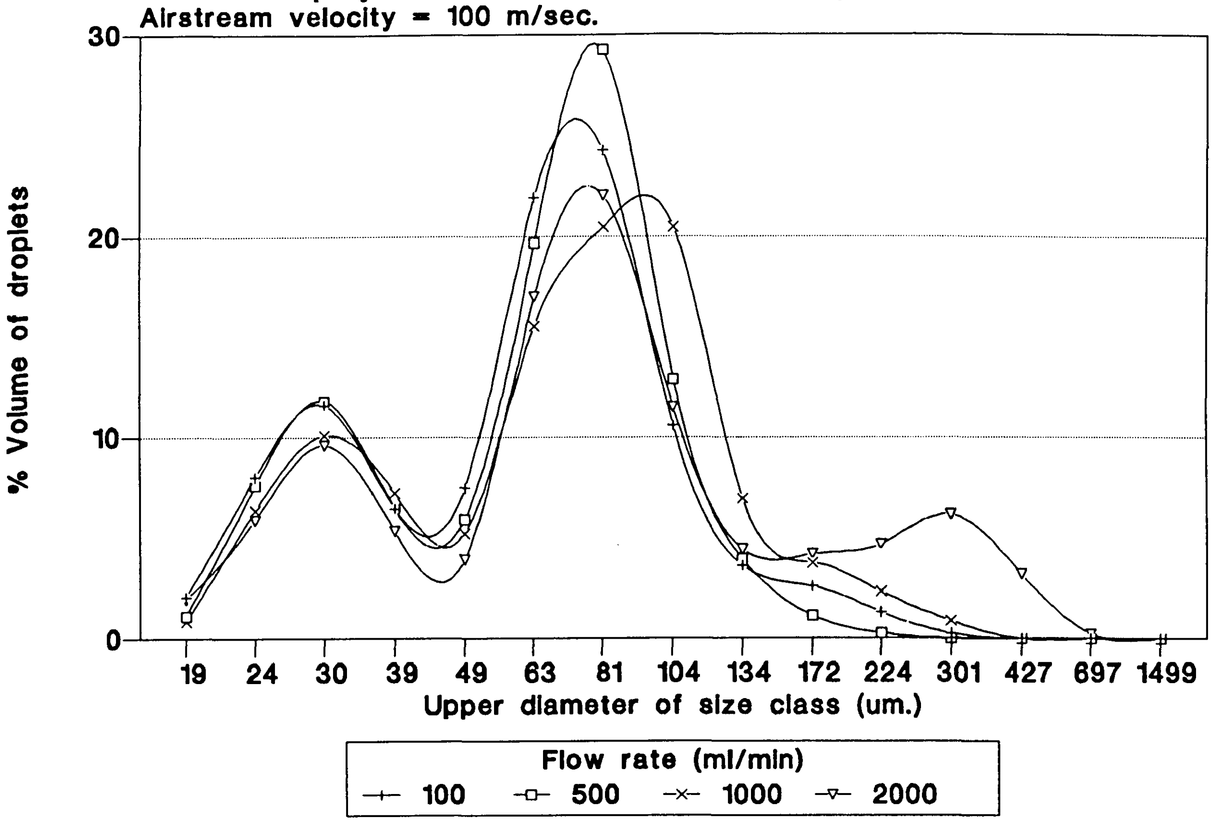


Fig3.52 Cumulative percentage vol. droplet distributions among size classes for Risella sprayed at different flow rates through AU8000 atomiser. Airstream velocity = 100 m/sec.

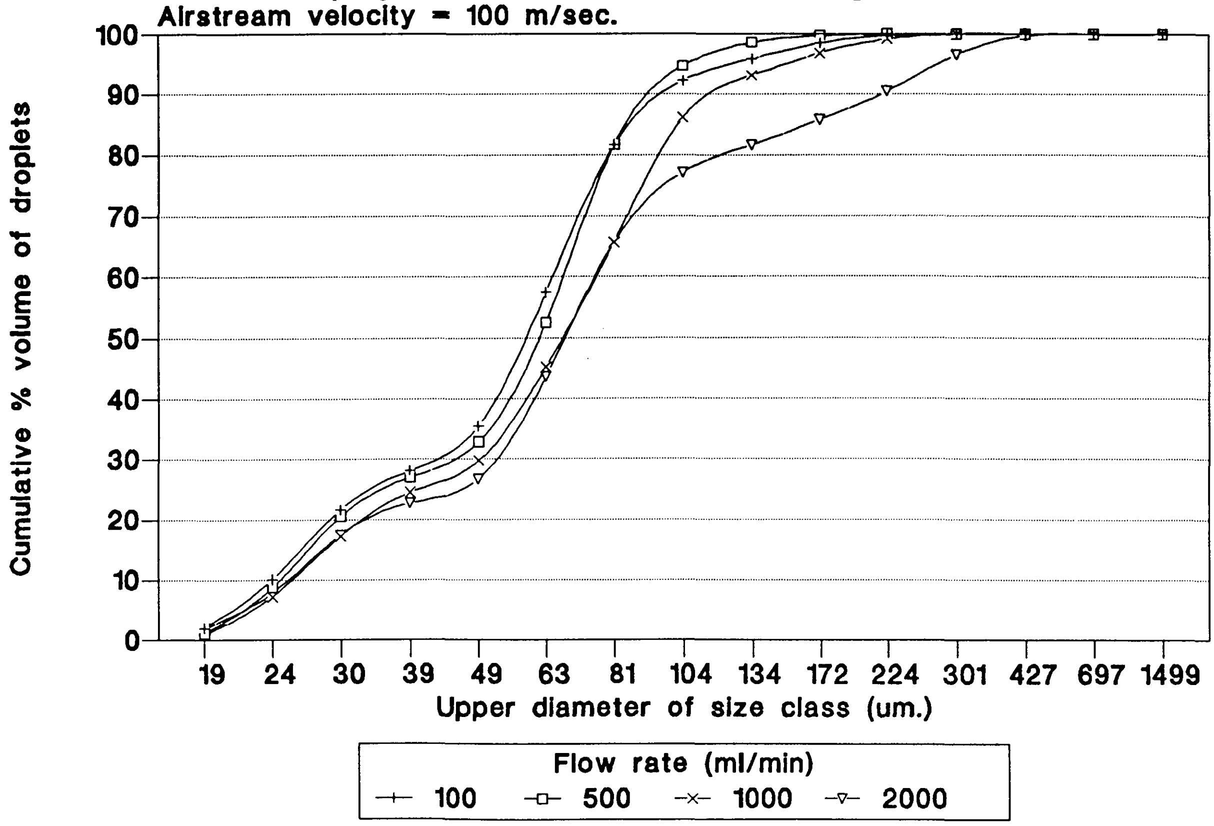


Fig. 3.53.

VMD against flow rate of water for NORIC7 at different rotation rates, with and without air-assistance.

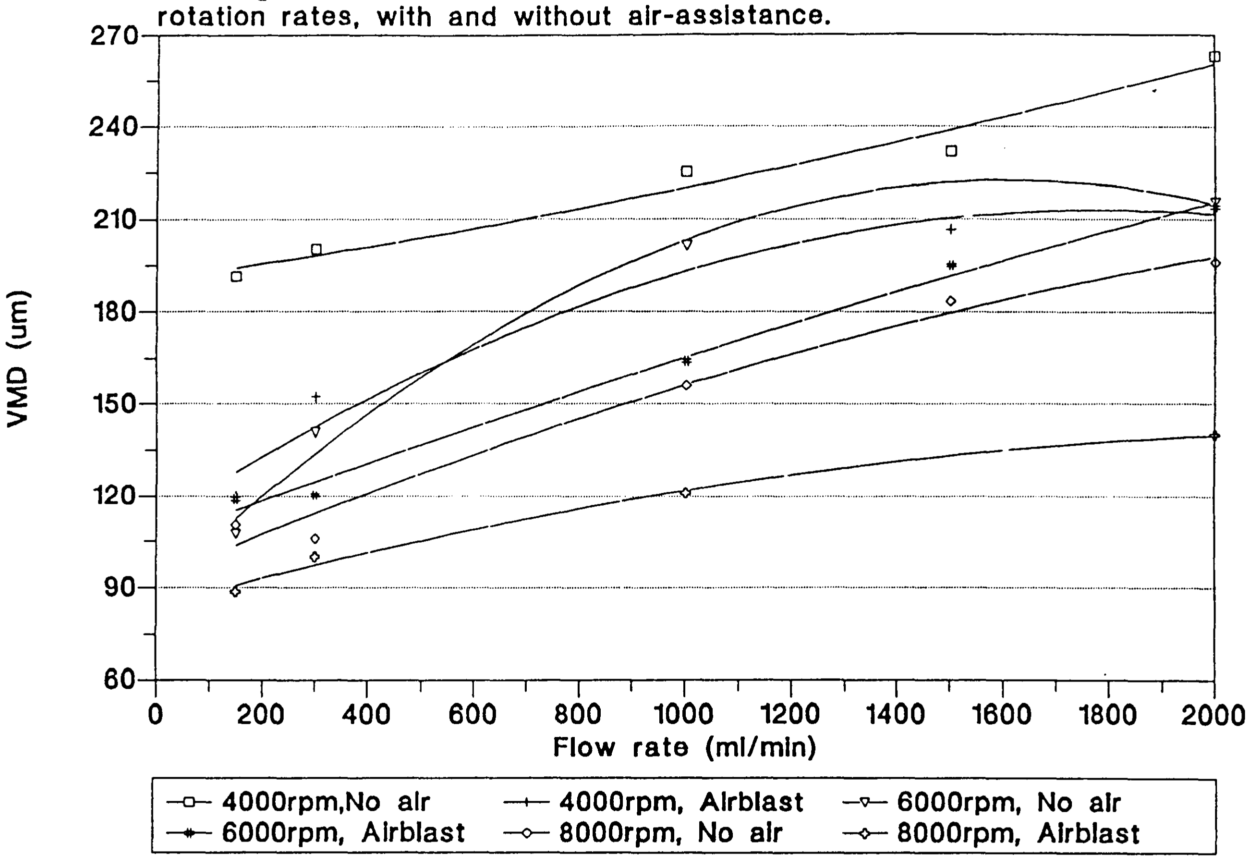
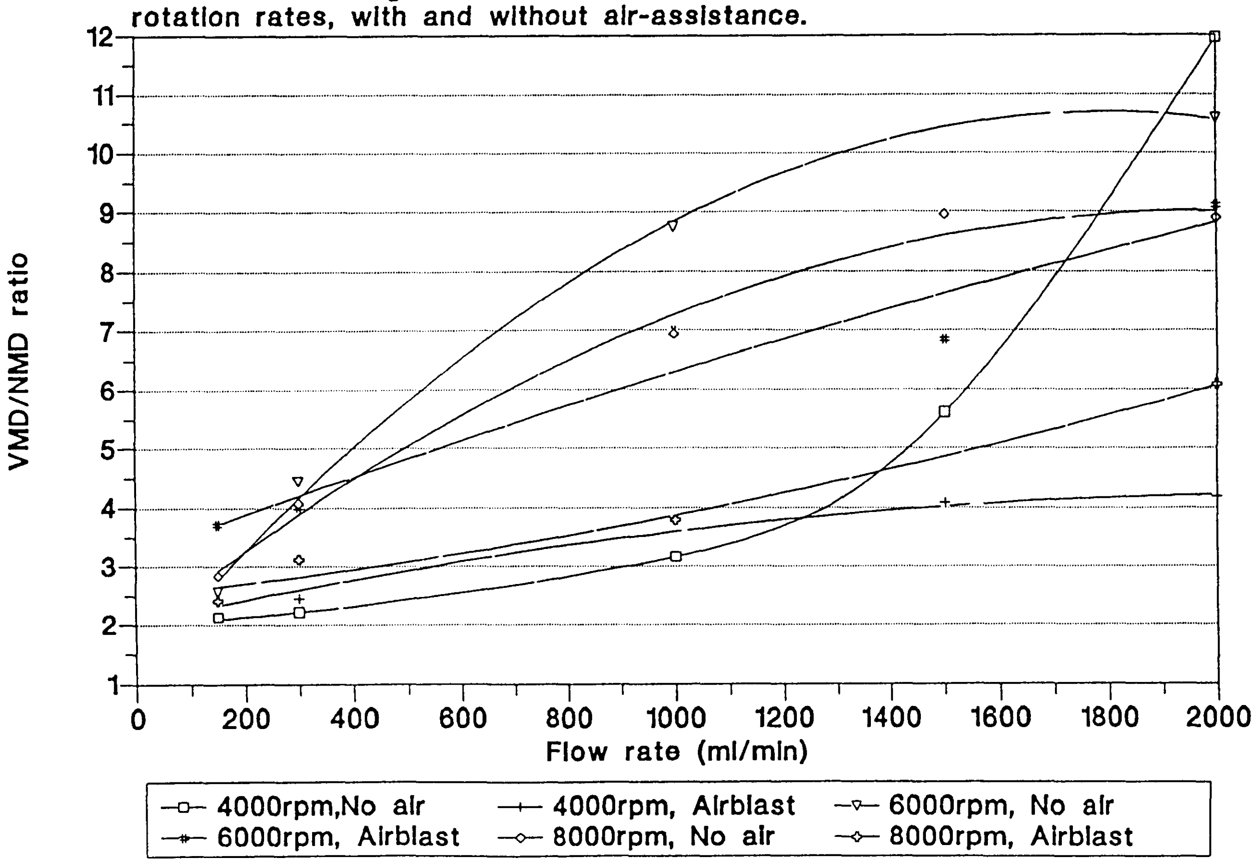


Fig. 3.54.

VMD/NMD ratio against flow rate for NORIC7 at different rotation rates, with and without air-assistance.



As flow rate increased, there was a larger difference between the VMD/NMD ratio of air- and non-air-assisted drums rotating at different rates. At 2000 ml/min, the VMD/NMD ratios were higher for drums operating without external air-assistance.

The distribution of droplets among size classes by volume changed with flow rate (Fig 3.55), thus at 250 and 1800 ml/min flow rate, the spectra were bi- and tri-modal; at 1000 ml/min the spectrum was bi-modal; and a mono-modal spectrum occurred at 500 ml/min.

The numeric droplet size spectra were bi-modal at 250 ml/min flow rate and mono-modal at higher flow rates (Fig 3.56). There were large numbers of droplets with diameter below 19 μm at 250 ml/min flow rate.

3.2.4. AU8000 CONFIGURATION

THE INFLUENCE OF CAGE MESH SIZE UPON DROPLET SIZE SPECTRA

Cage mesh size (m) did not have a large effect upon the spray VMD (Fig 3.57) and VMD/NMD ratio (Fig 3.58) at different flow and rotation rates. The diamond mesh (Z) produced the largest VMD at flow rates up to 1000 ml/min.

Fig. 3.55. Percentage droplet distributions among size classes by volume for water+Agral sprayed through Noric7 atomiser.

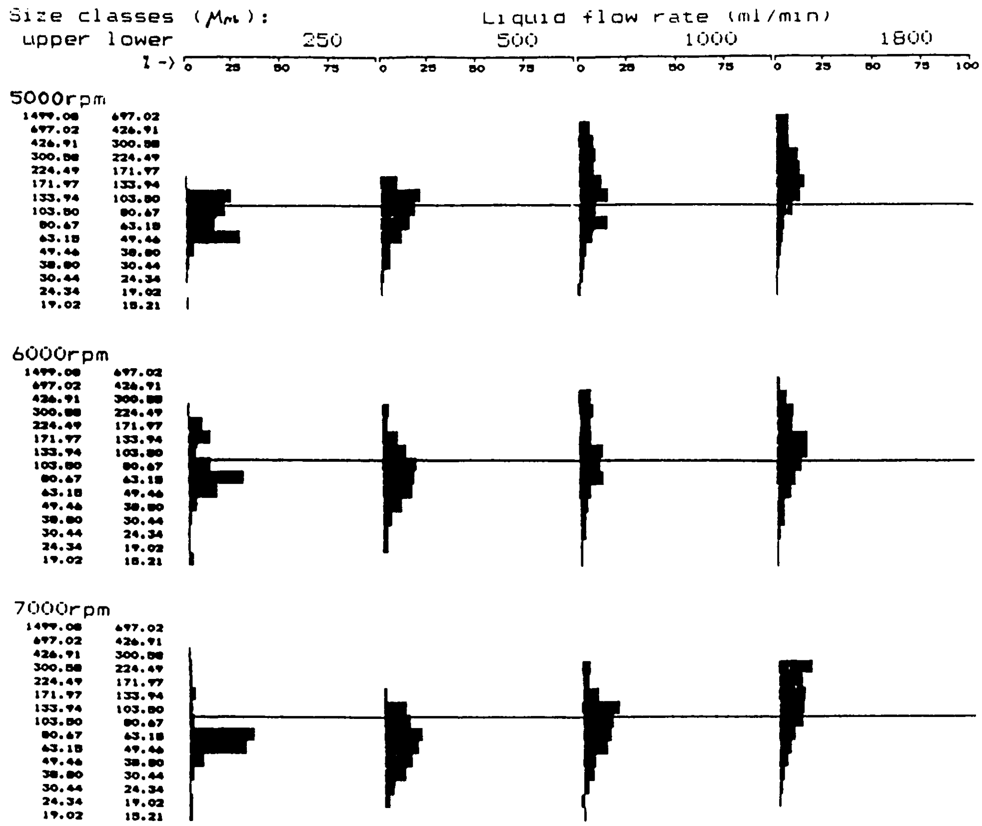


Fig. 3.56. Percentage droplet distributions among size classes by number for water+Agral sprayed through Noric7 atomiser.

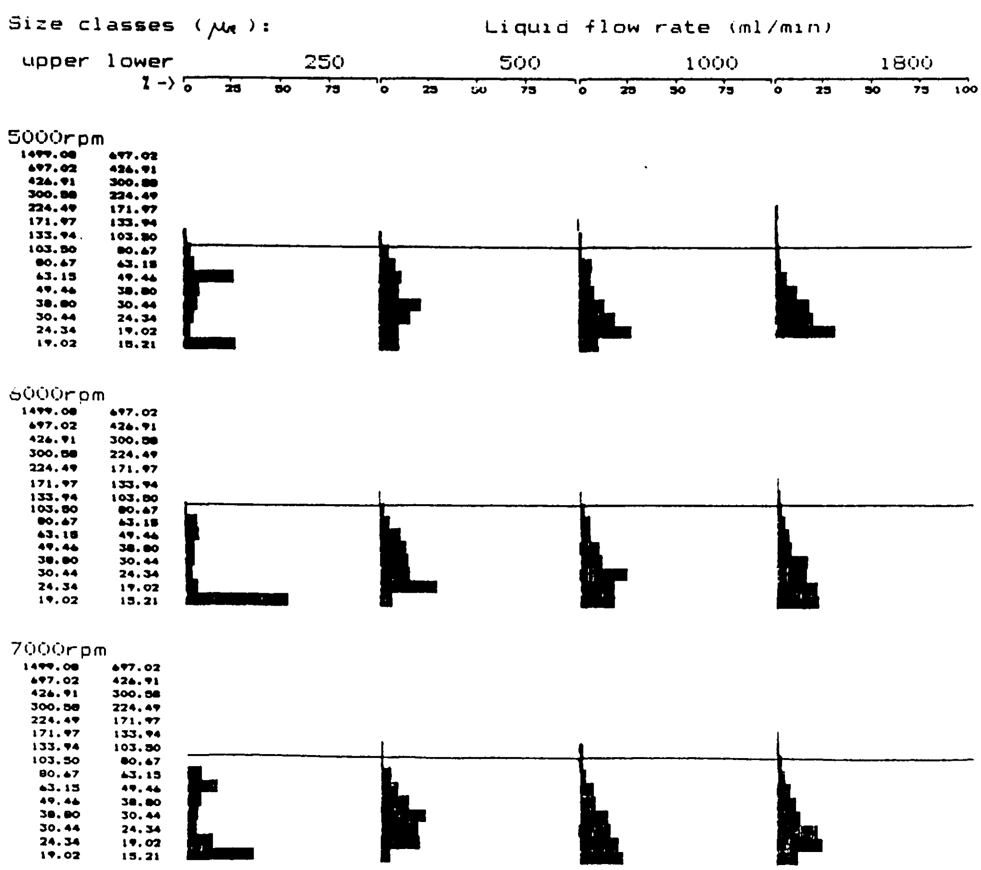


Fig.3.57 VMD against flow rate of water+Agral sprayed through different mesh sizes at 13000 and 6500rpm. Airspeed=116m/sec.

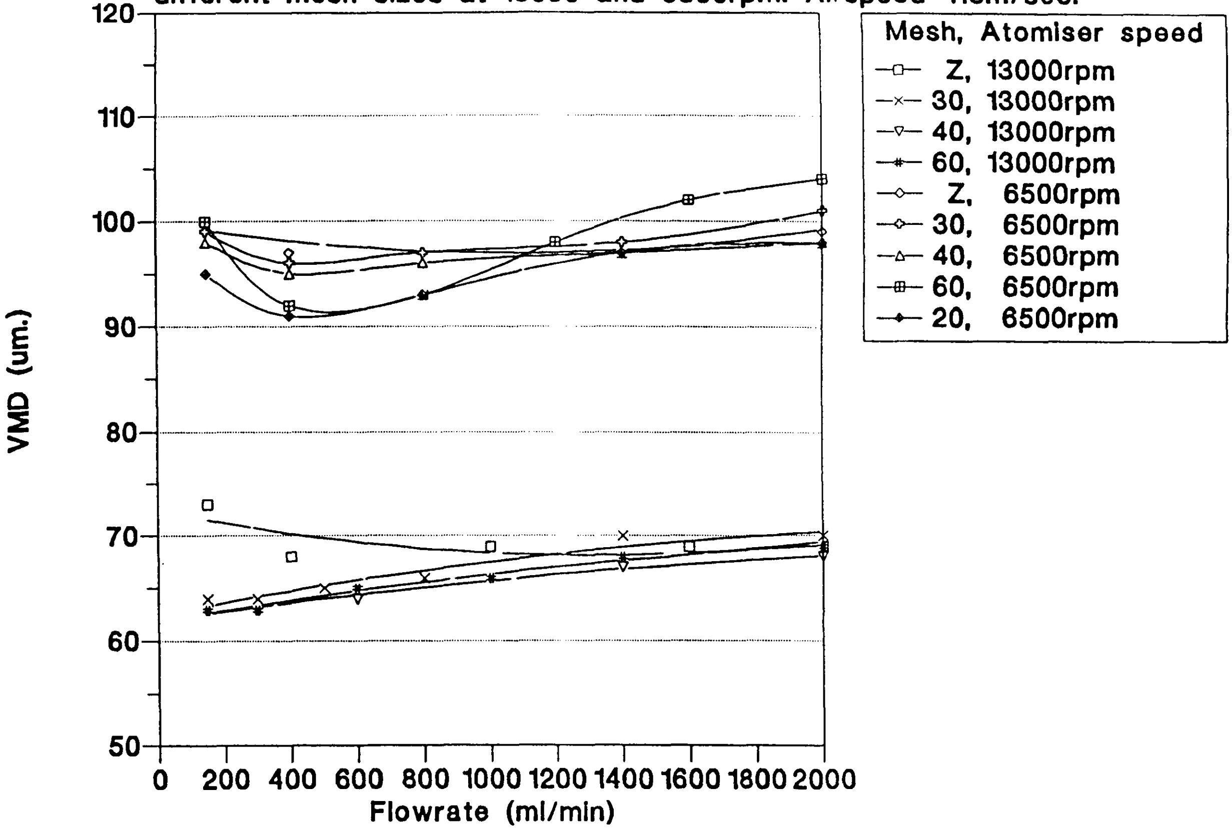
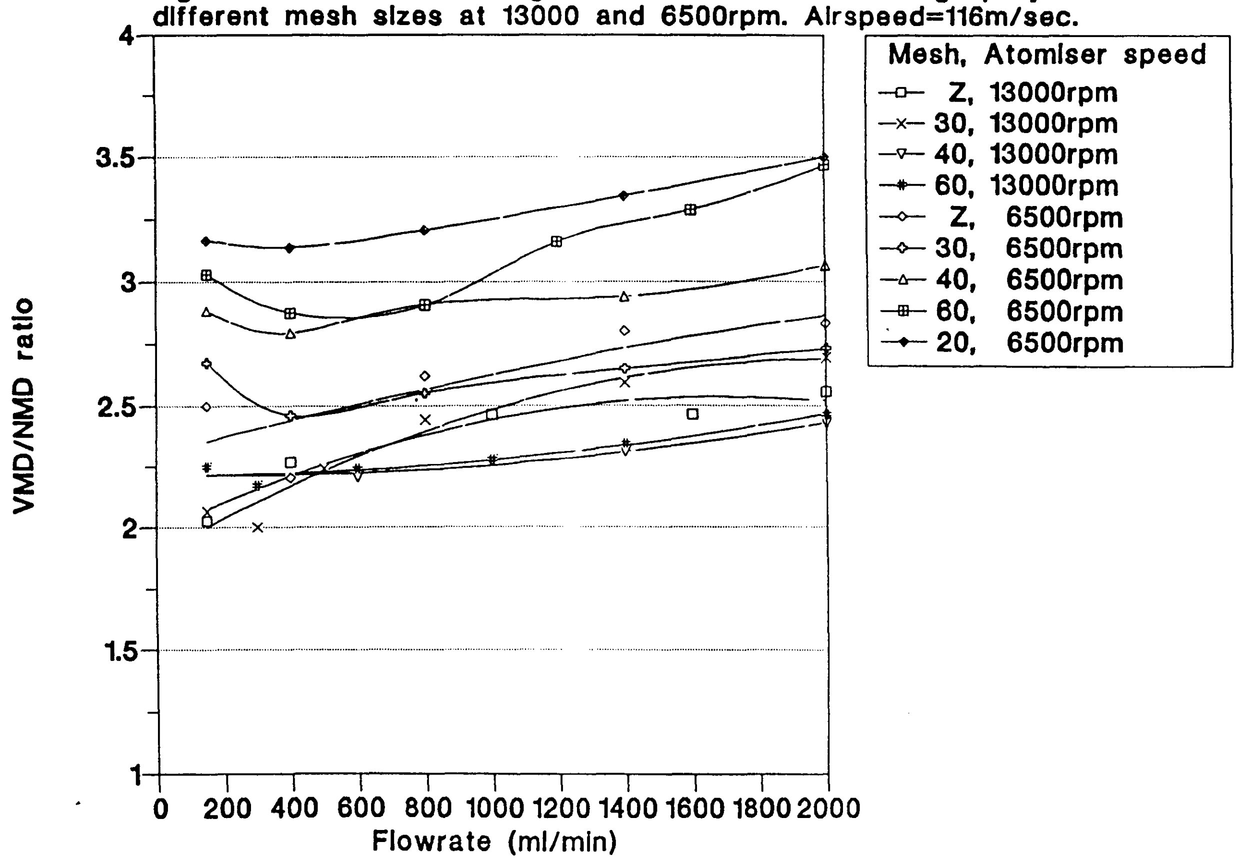


Fig.3.58 VMD/NMD ratio against flow rate of water+Ag sprayed with different mesh sizes at 13000 and 6500rpm. Airspeed=116m/sec.



The triangular diffuser design currently used in AU8000 atomisers (diffuser 1) produced lower VMD values than the rectangular (diffuser 2) and half-rectangular (diffuser 3) designs (Fig 3.57). However, diffuser 3 produced spray with relatively low VMD/NMD ratios (Fig 3.58).

3.2.5. SLOTTED ROTARY DRUM ATOMISER CONFIGURATION

At a flow rate of 800 ml/min and a rotation rate of 6000 rpm, the VMD varied between 105 and 162 μm for the 95 mm diameter drums (M1-M4) and 102 to 139 μm for the 88 mm drums (M5-M10) (Table 3.1). All drums produced lower or equal VMD/NMD ratios when rotated in the same direction as the vanes (for example clockwise rotation of drums with clockwise-orientated vanes).

Fig.3,59 VMD against flow rate of water+Agral sprayed through AU8000 with different diffusers. Rotation rate = 13000rpm.

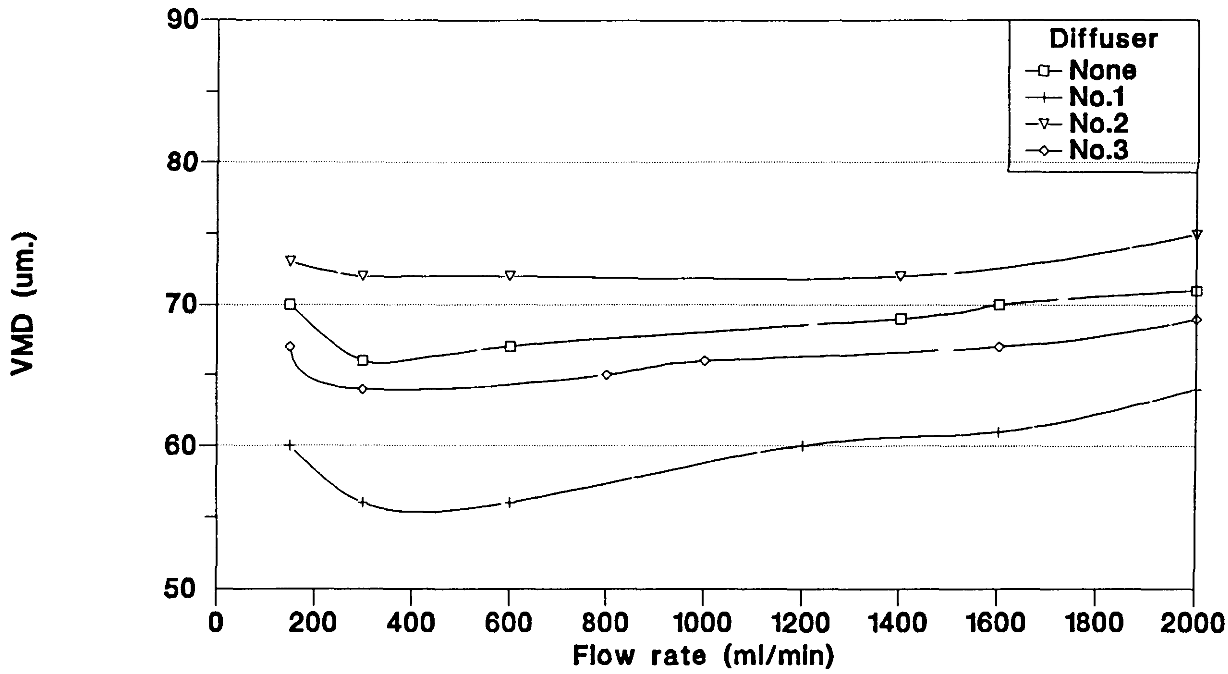


Fig.3,60 VMD/NMD ratio against flow rate of water+Ag sprayed from AU8000 with different diffusers. Rotation rate = 13000rpm.

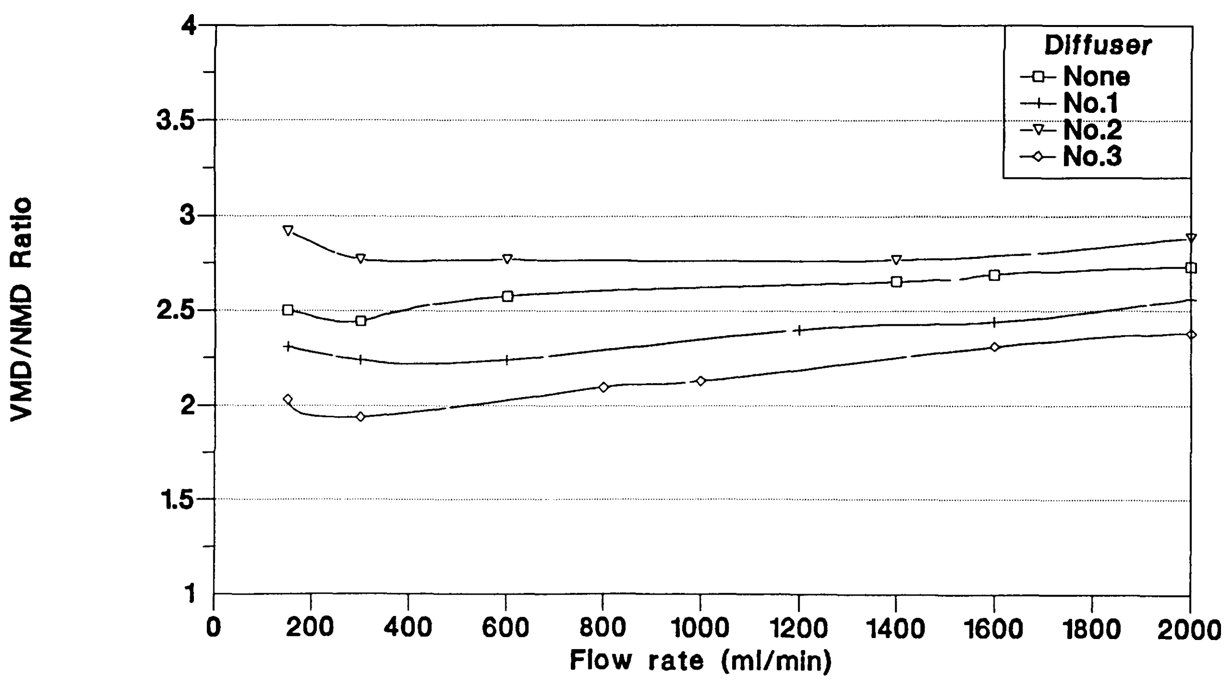


Table 3.1. Droplet size spectra at flow rate of 800 ml/min and rotation rate of 6000 rpm for different drum designs and rotation directions.

Drum no.	Rotation direction relative to vanes	VMD µm	NMD µm	VMD/NMD ratio	VAD µm
M1	Equal	137	30	4.61	67
''	Opposite	128	28	4.62	57
M2	Equal	162	54	3.03	98
''	Opposite	118	29	4.03	62
M3	Equal	105	44	2.40	69
''	Opposite	144	26	5.48	58
M4	Equal	147	31	4.70	70
''	Opposite	130	28	4.70	58
M5	Equal	135	47	2.89	85
''	Opposite	105	30	3.45	58
P6	Equal	133	40	3.31	77
''	Opposite	142	26	5.46	58
P7	Equal	104	40	2.63	67
''	Opposite	120	31	3.82	65
P8	Equal	139	43	2.44	70
''	Opposite	125	36	3.48	71
P9	Equal	124	38	3.23	74
''	Opposite	110	33	3.38	64
P10	Equal	102	31	3.33	56
''	Opposite	137	39	3.47	74

Differences in the VMD/NMD ratio with rotation direction increased with the addition of teeth to the inner peripheral surface of the vanes. The addition of teeth to only the outer peripheral vane rims did not cause a large change in the droplet size spectrum.

The toothed drum with grooves on the inner vane surfaces produced a lower VMD and similar VMD/NMD ratio to the toothed drum without grooves.

SHROUD POSITION

Differences in the VMD and VMD/NMD ratios produced when Noric3 was operated with the liquid injector at different orientations relative to the shroud window releasing spray across the laser beam tended to increase with increasing flow rate and rotation rate (Figs 3.61 to 3.68).

LIQUID DISTRIBUTION SYSTEM

A reduction in the VMD and and the VMD/NMD ratio of the spray produced by shrouded Noric7 was achieved using two liquid injection points compared to a single point (Figs 3.69 and 3.70).

The narrowest Noric slotted rotary drum droplet spectra were produced using a shroud and two liquid injection points. However, the volumetric droplet size spectra were generally bi- and tri-modal in form (Figs 3.71 to 3.76).

3.3. DISCUSSION.

3.3.1. DEVELOPMENT OF EMPIRICAL MODELS FOR THE PREDICTION OF DROPLET SIZE SPECTRA

The experimental data were analysed by multiple linear regression to develop empirical models for predicting droplet size spectra from each atomiser. The independant

Fig 3.61 VMD against liquid injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 250 ml/min

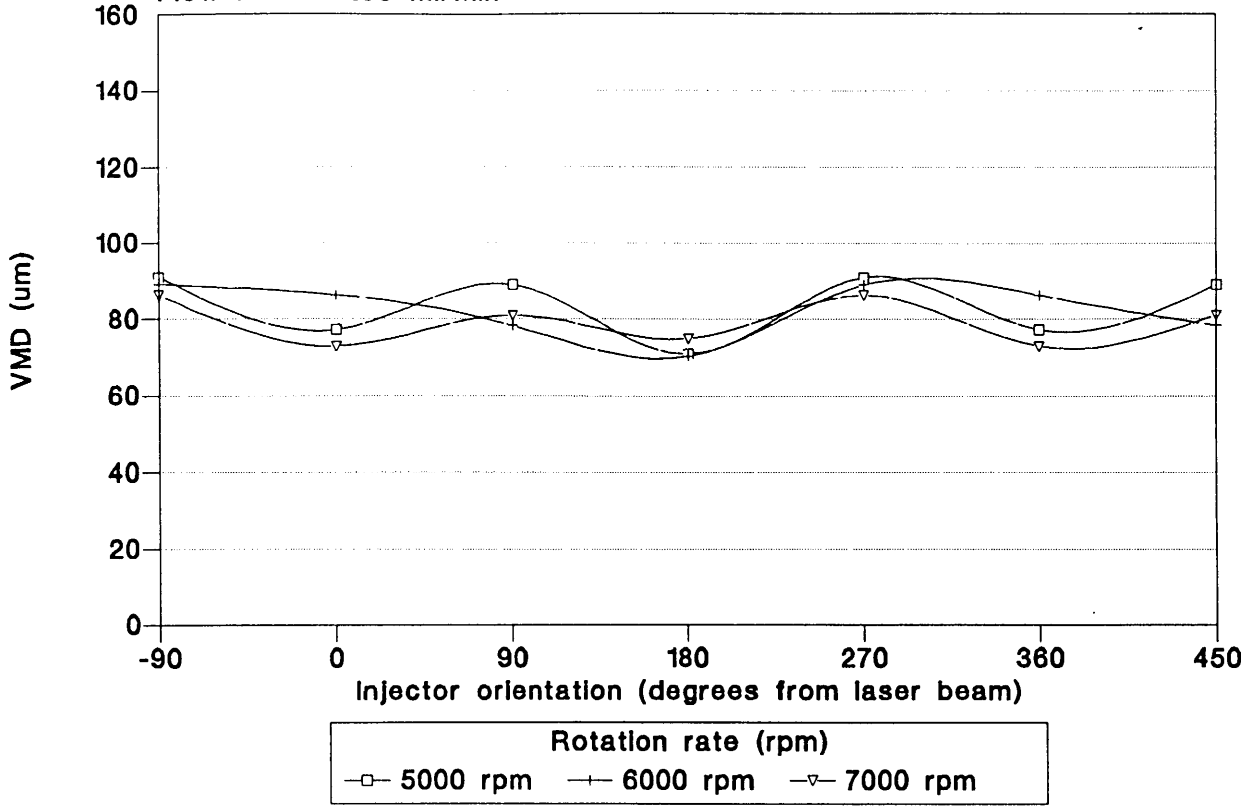


Fig 3.62 VMD against liquid injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 500 ml/min

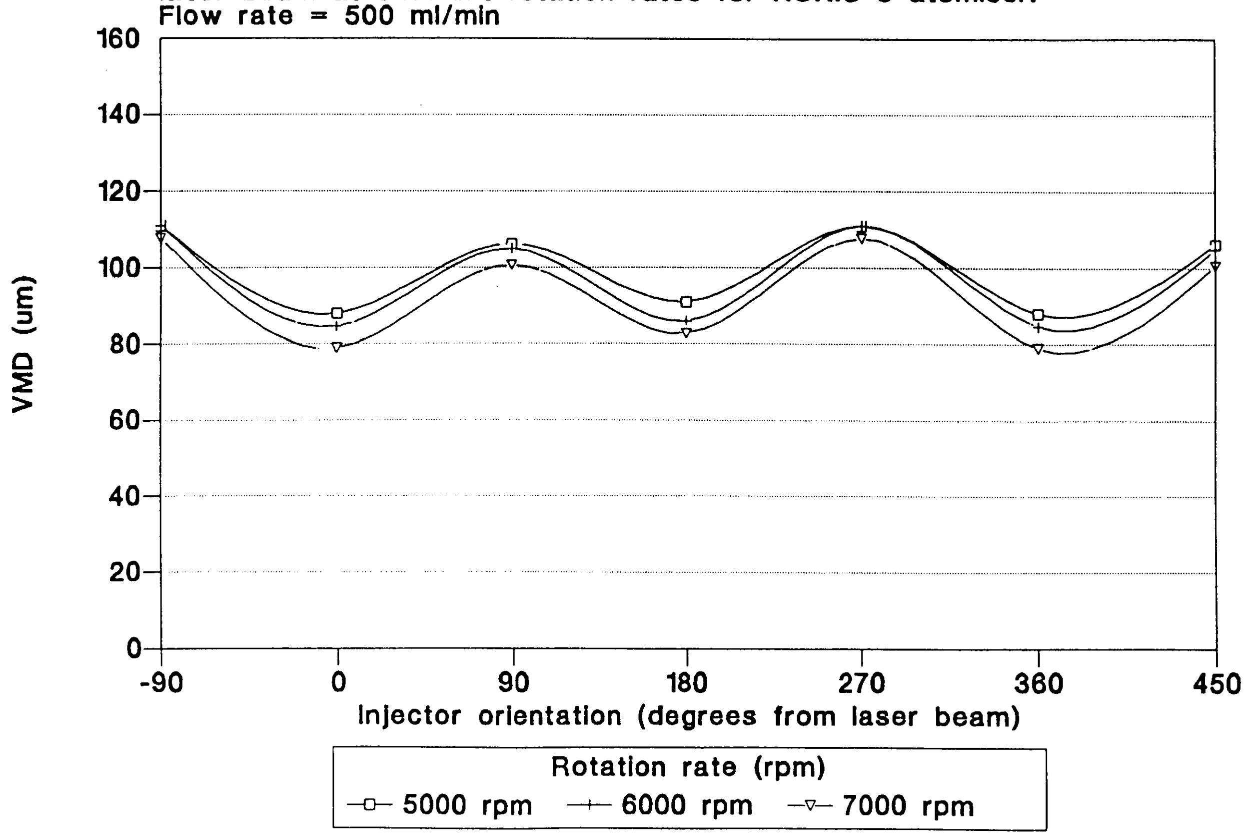


Fig 3.63 VMD against liquid injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 1000 ml/min

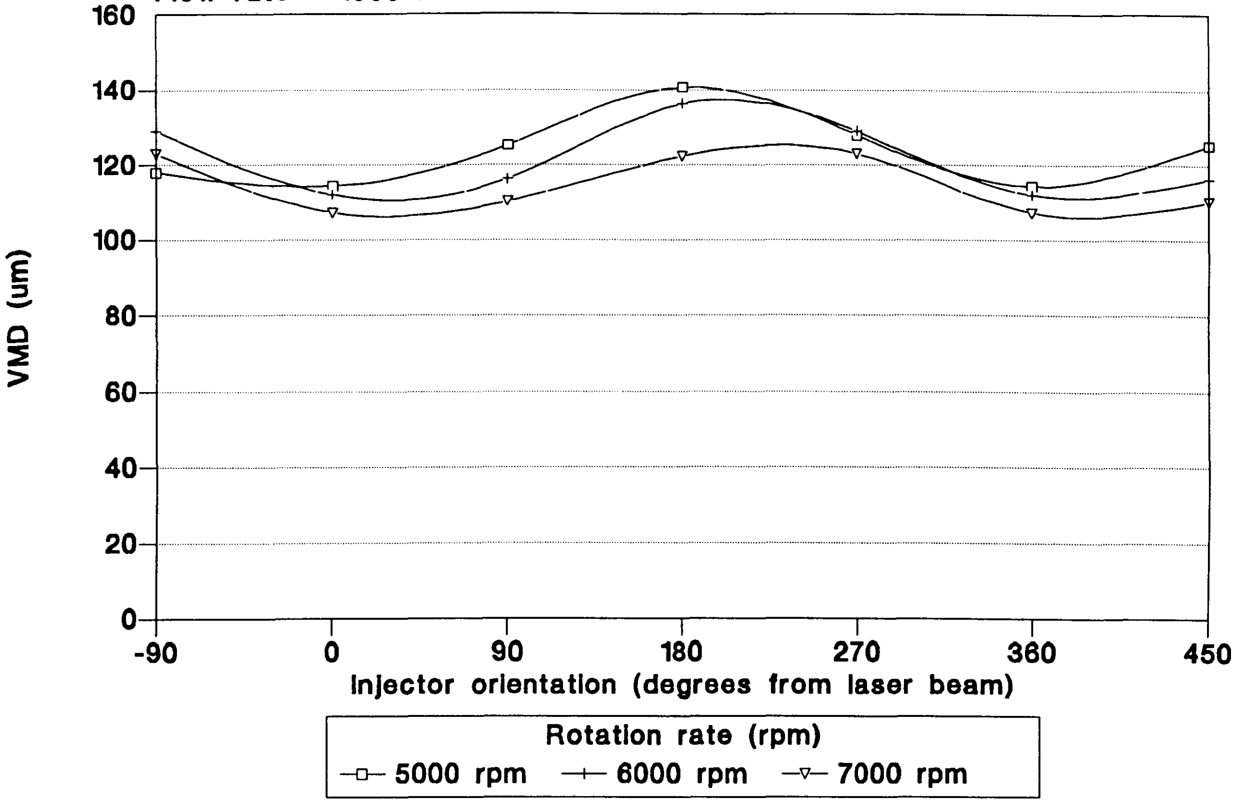


Fig 3.64 VMD against liquid injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 1800 ml/min

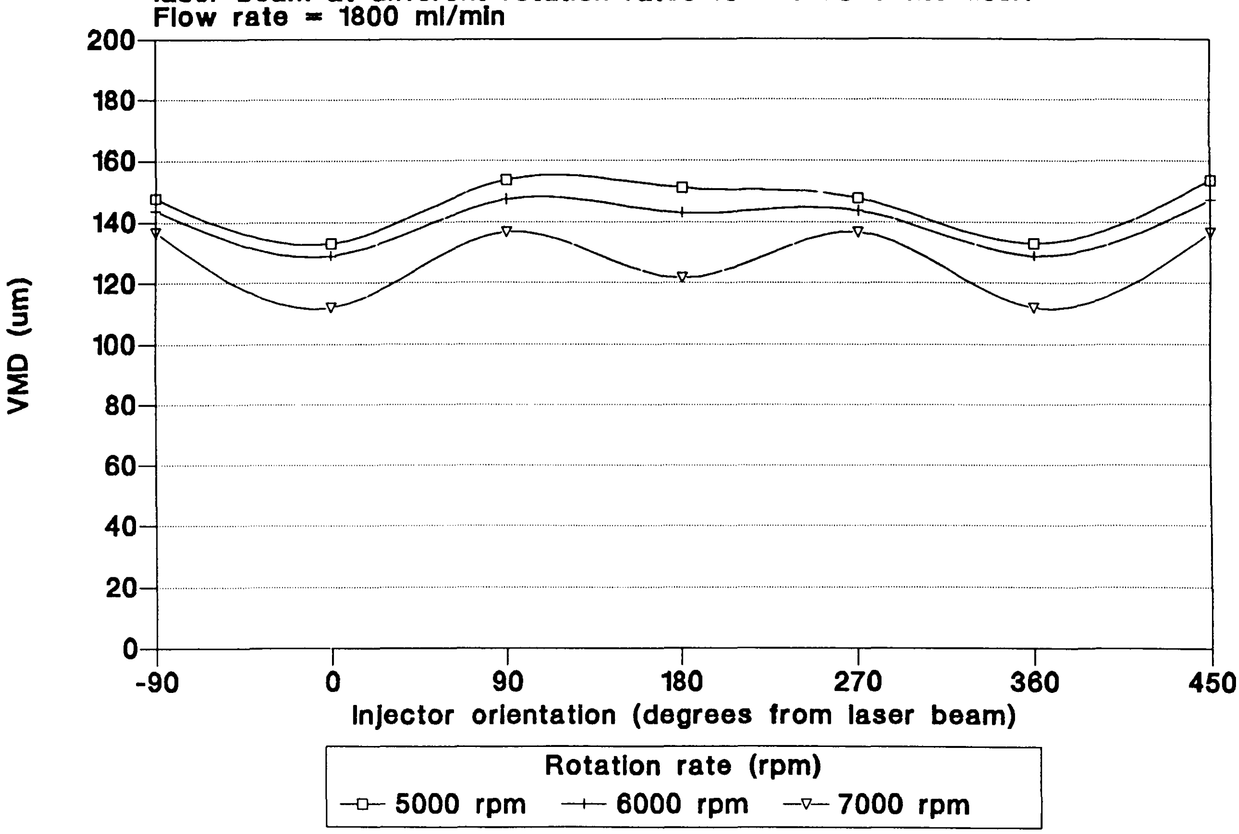


Fig 3.65 VMD/NMD ratio against injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 250 ml/min

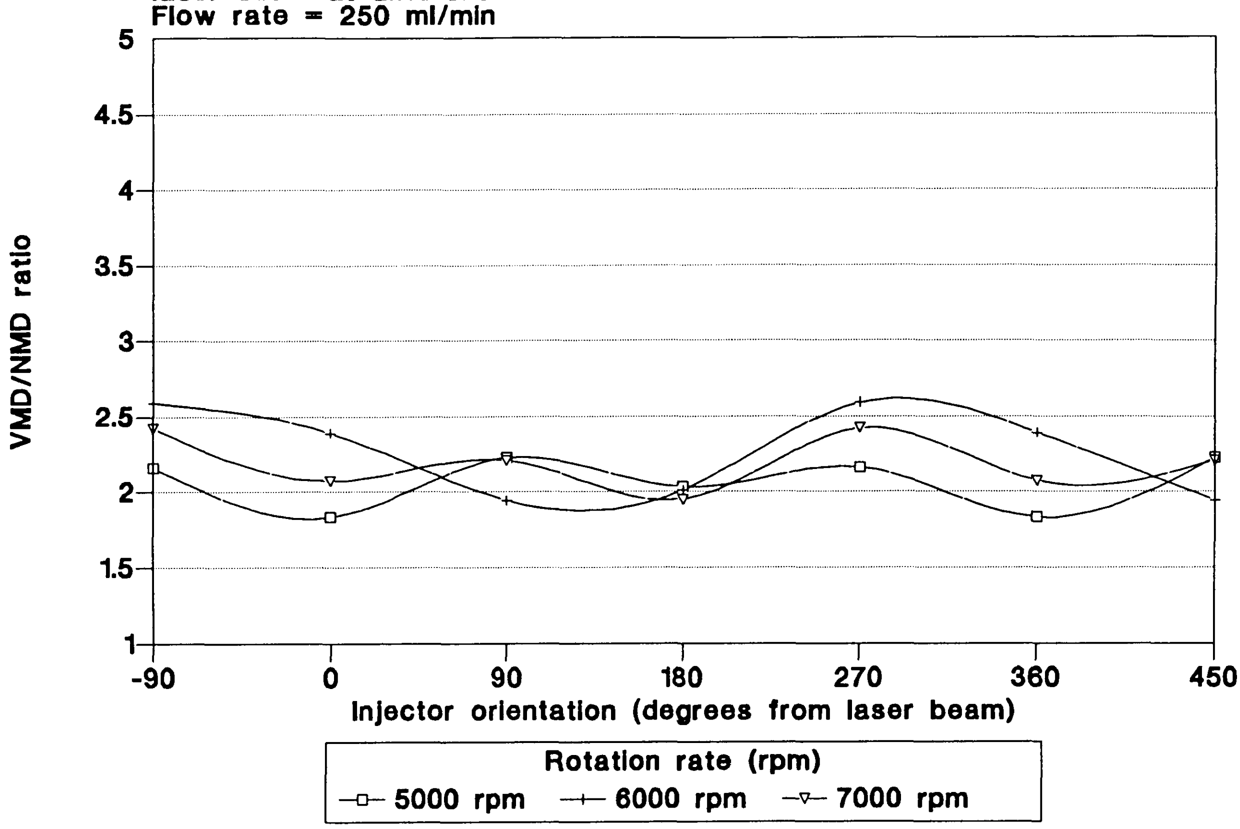


Fig 3.66 VMD/NMD ratio against injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 500 ml/min

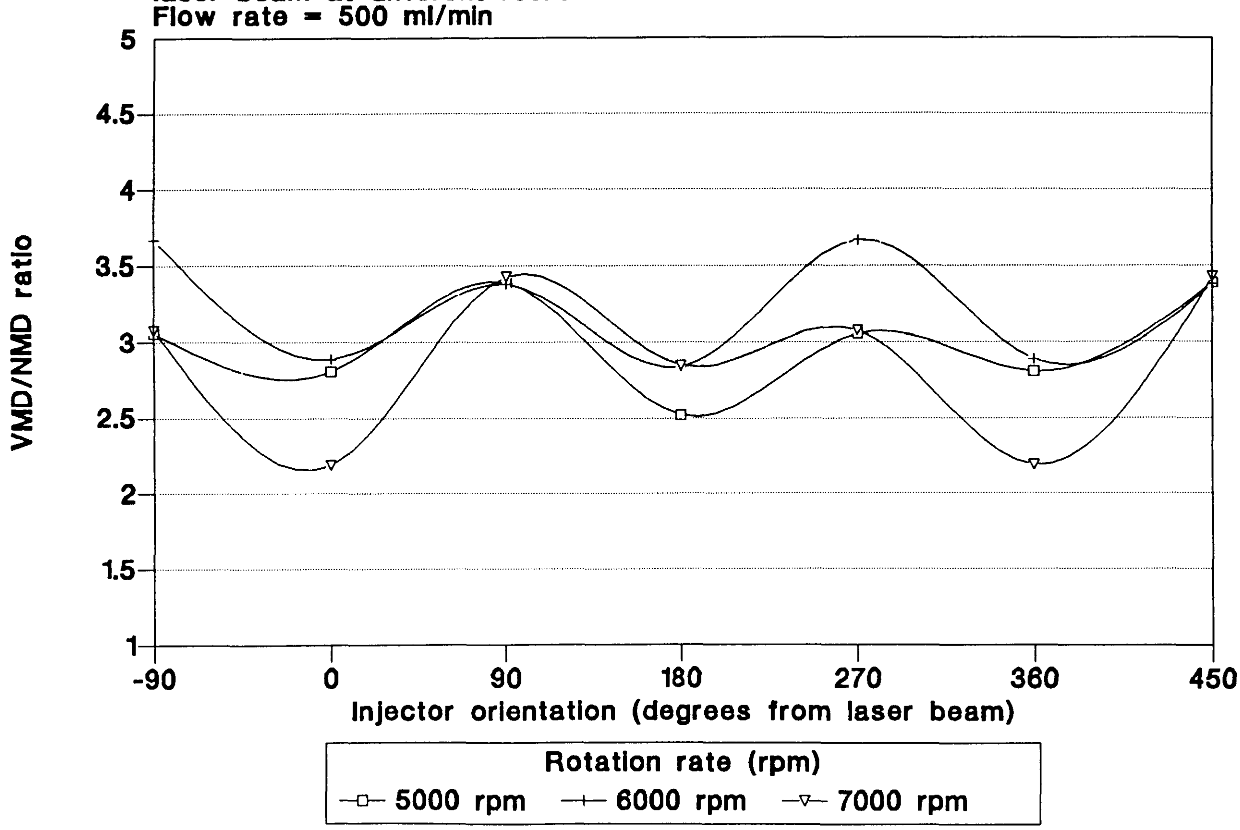


Fig 3.67 VMD/NMD ratio against injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 1000 ml/min

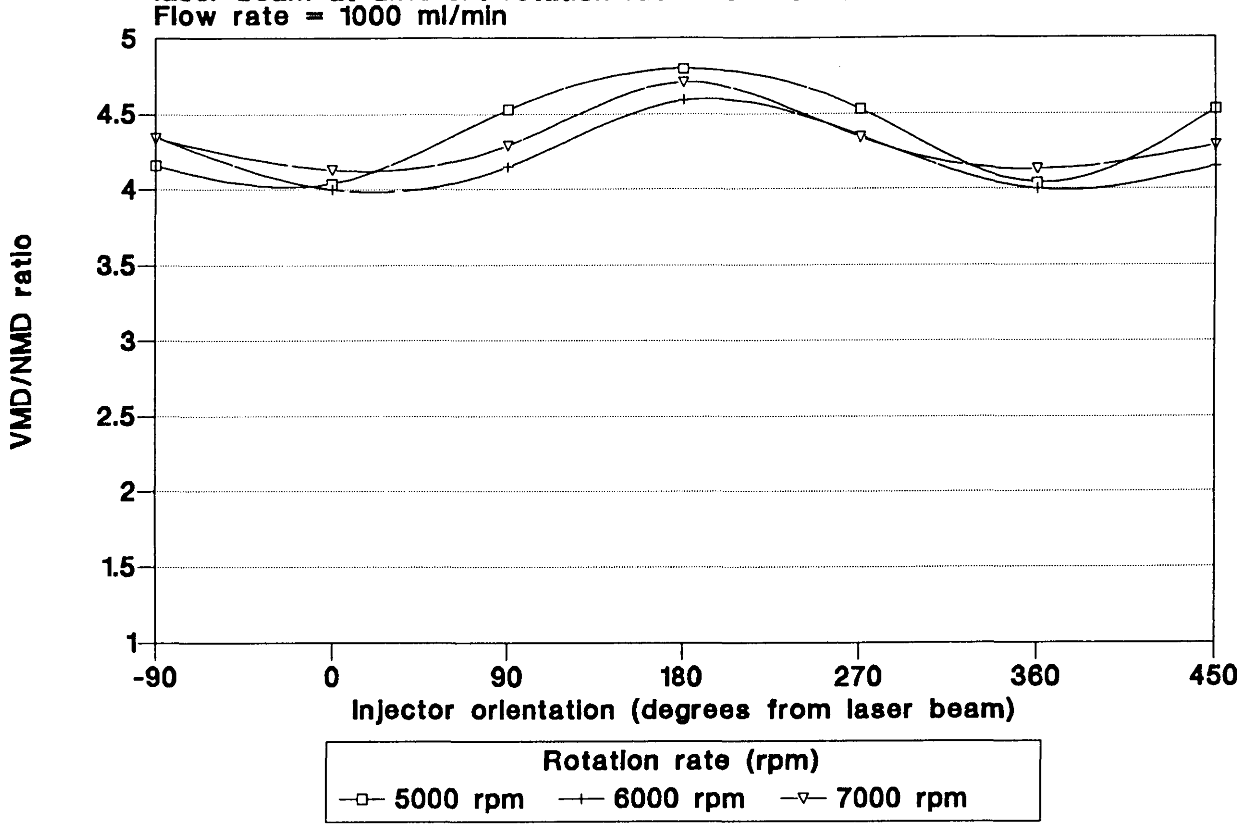


Fig 3.68 VMD/NMD ratio against injector orientation relative to laser beam at different rotation rates for NORIC 3 atomiser. Flow rate = 1800 ml/min

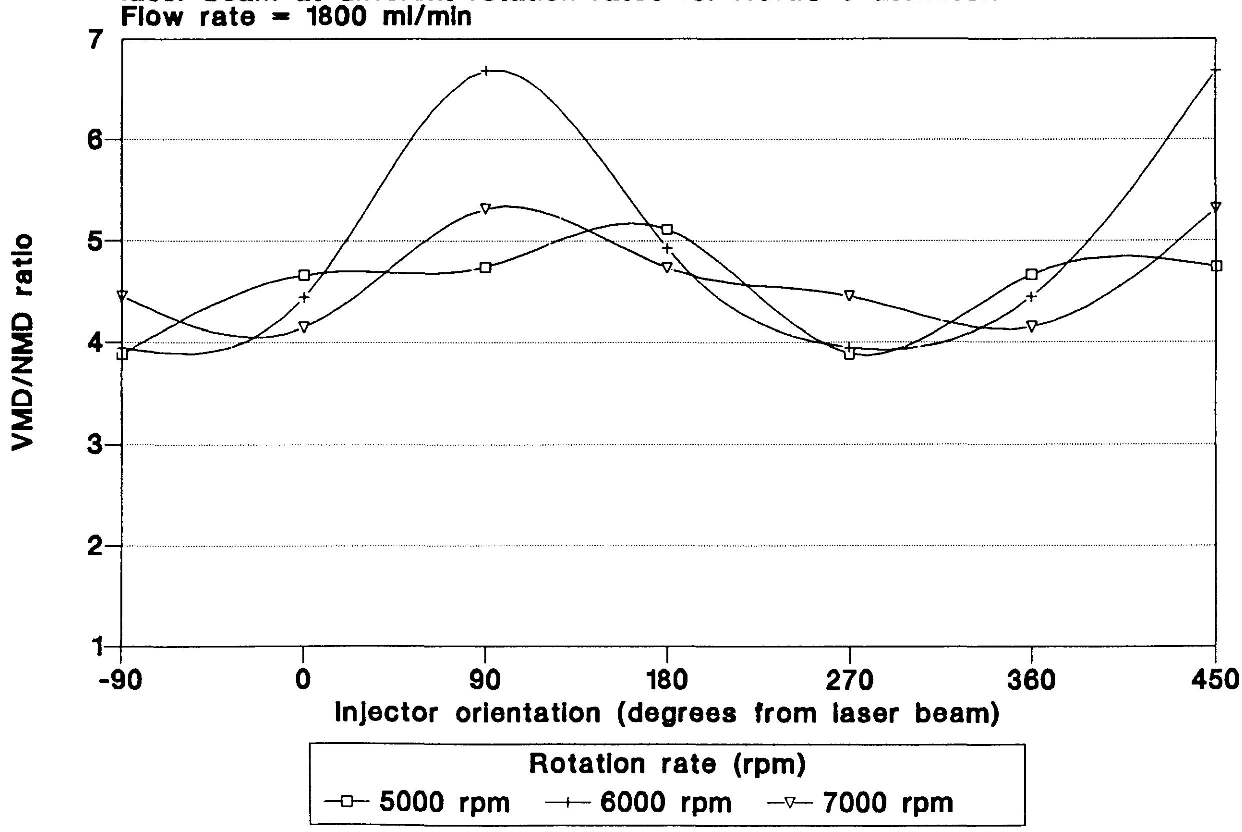


Fig 3.69 VMD against flow rate of water+Agral sprayed through single and twin injectors in Noric7 atomiser rotating at different rates.

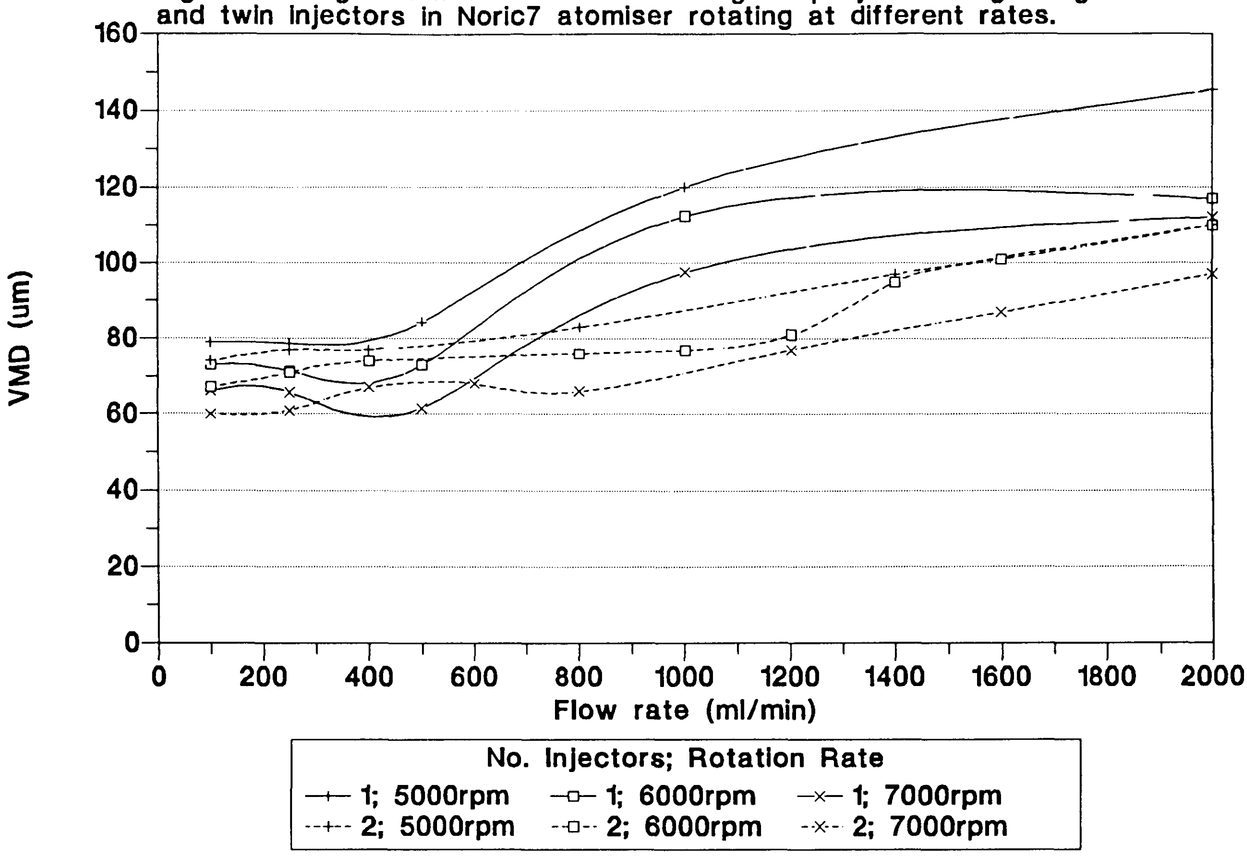


Fig 3.70 VMD/NMD ratio against flow rate of water+Agral sprayed through single and twin injectors in Noric7 atomiser rotating at different rates.

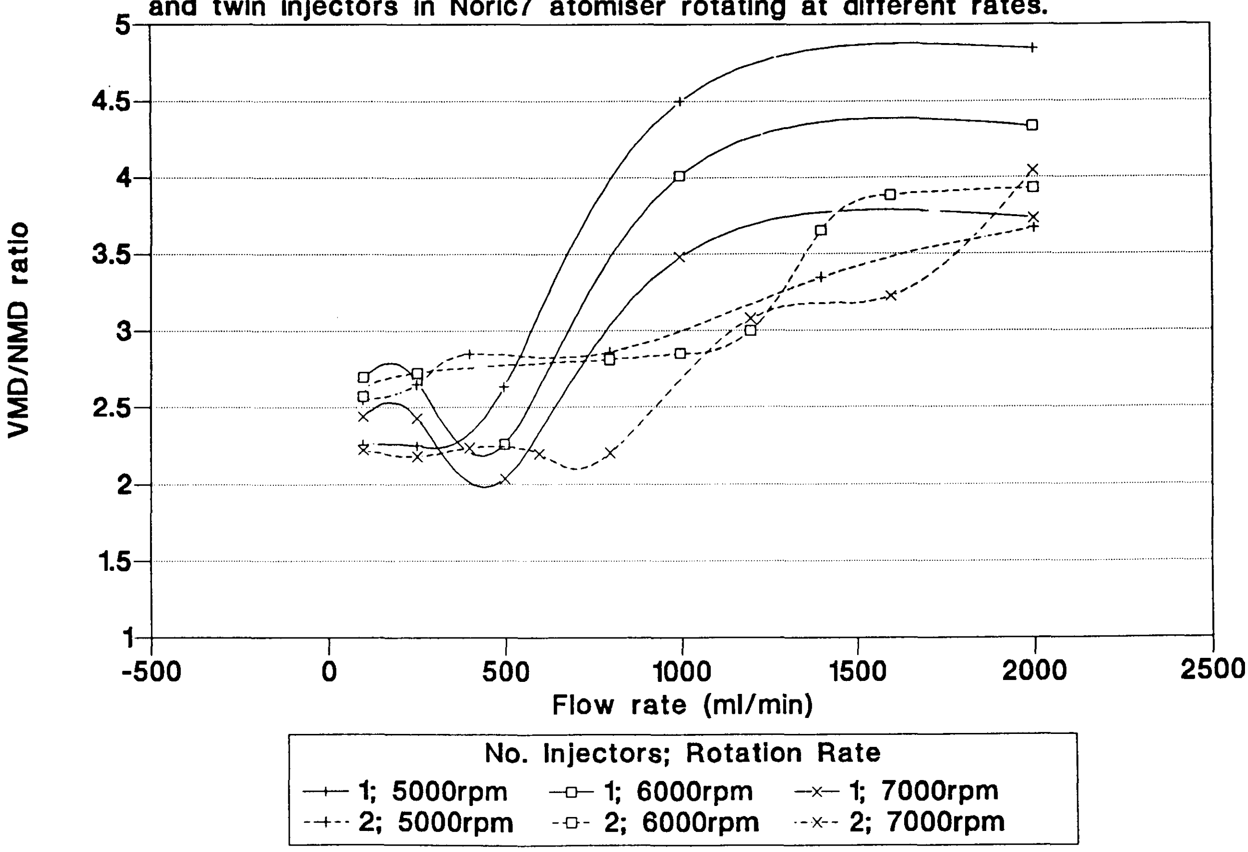


Fig3.71 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=5000rpm

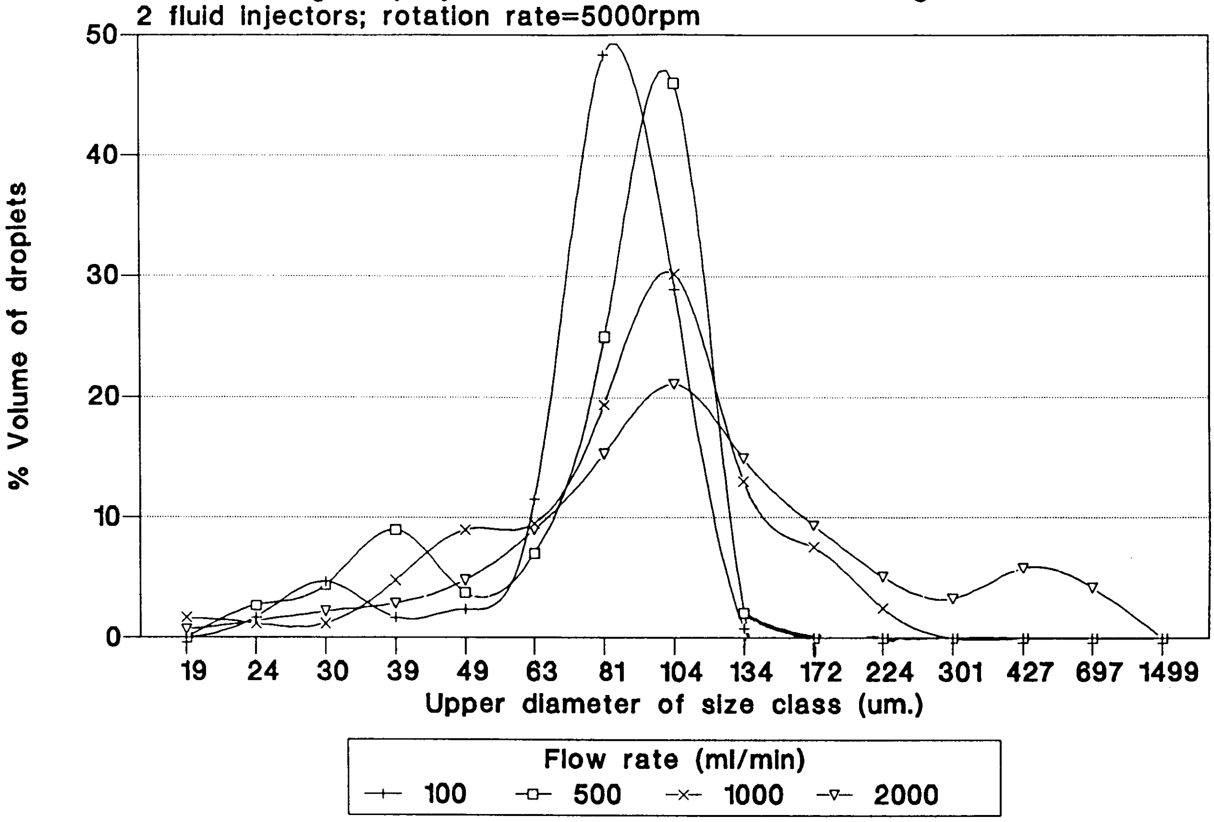


Fig 3.72 Cumulative percentage volume droplet distributions among size clas for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=5000rpm

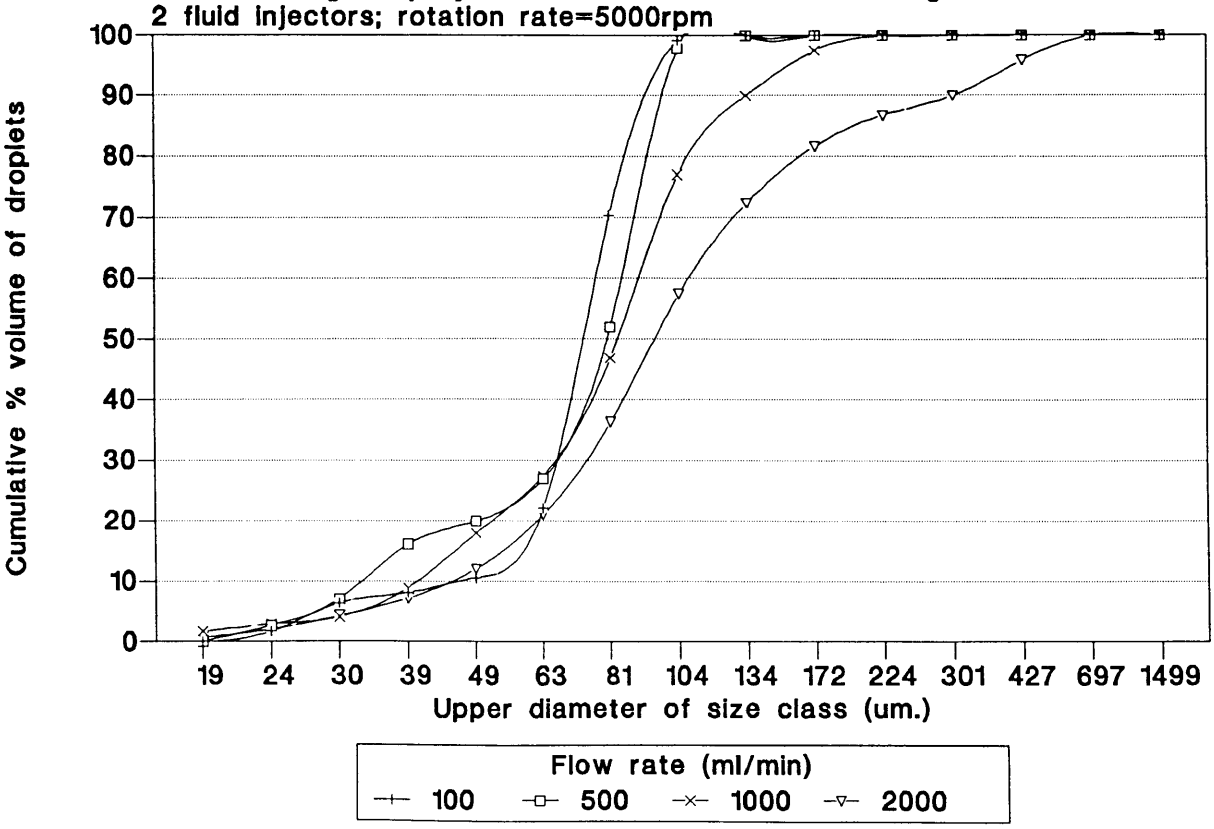


Fig 3.73 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=6000rpm

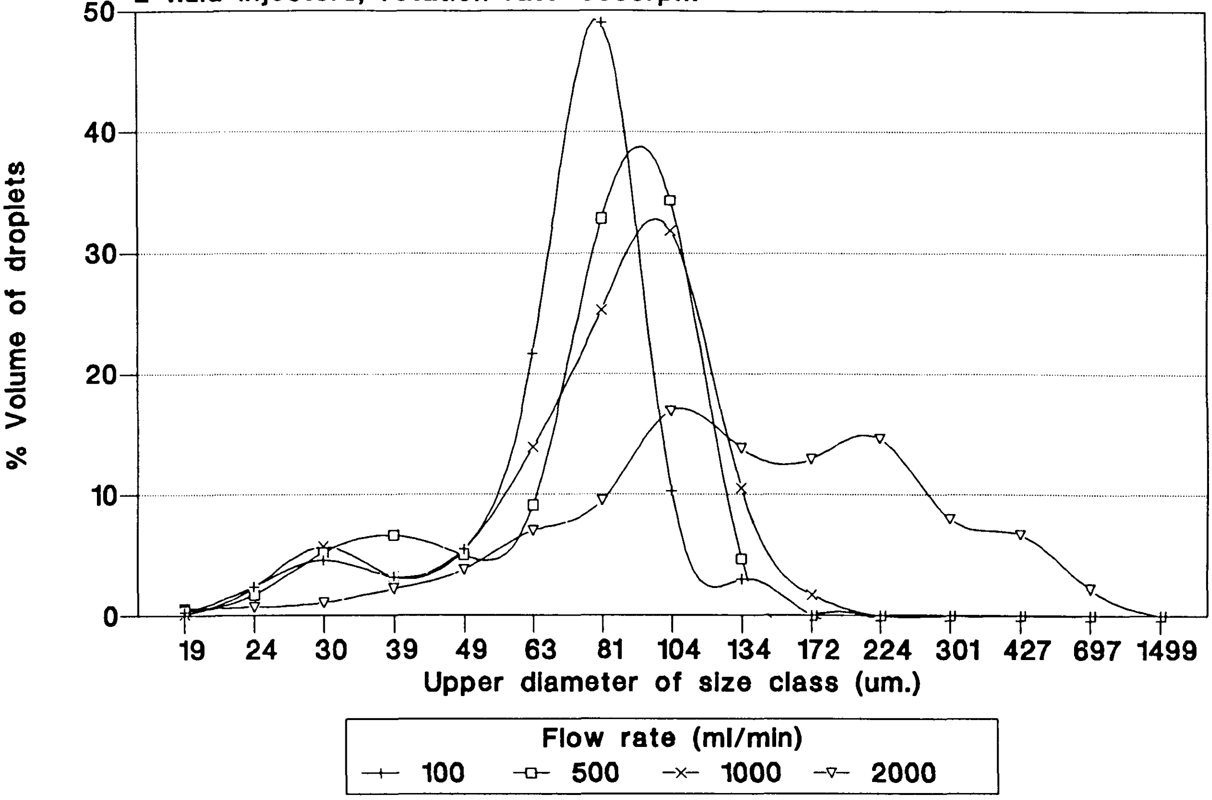


Fig 3.74 Cumulative percentage volume droplet distributions among size clas for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=6000rpm

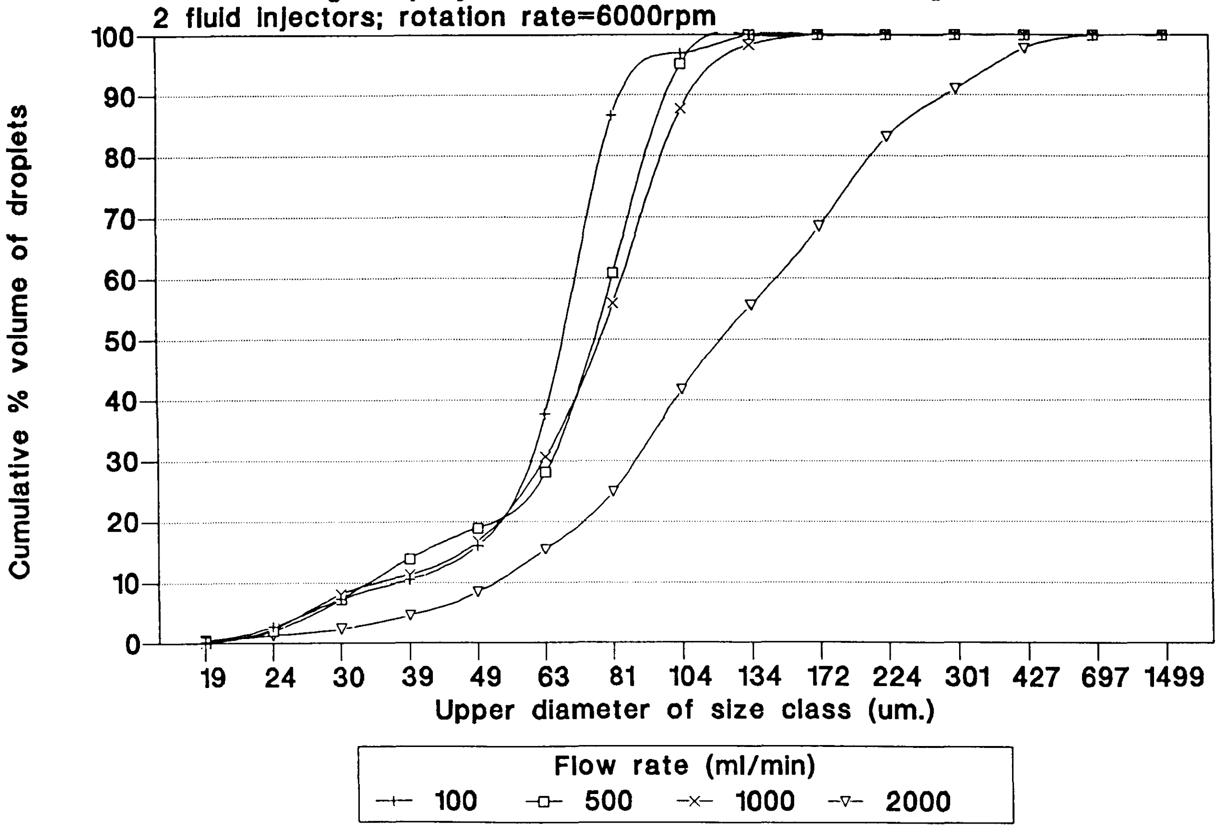


Fig 3.75 Percentage volume droplet distributions among size classes for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=7000rpm

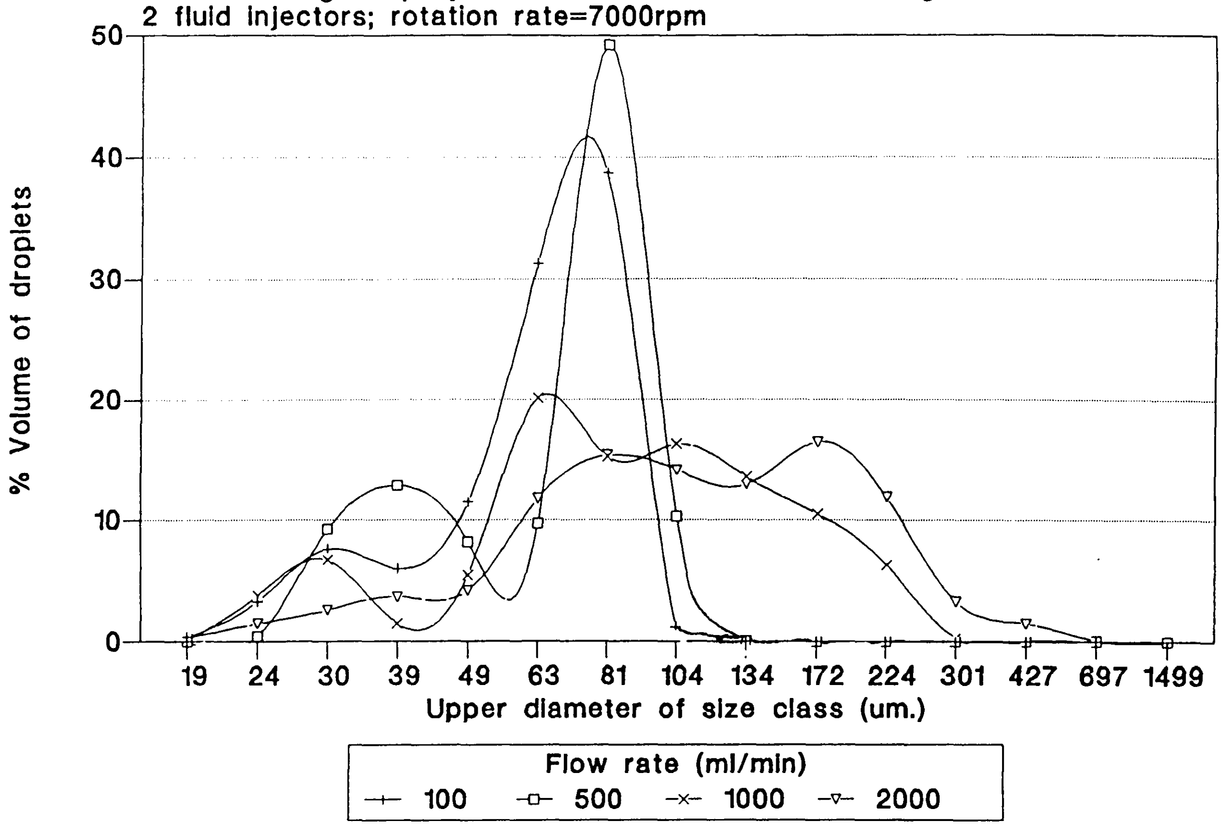
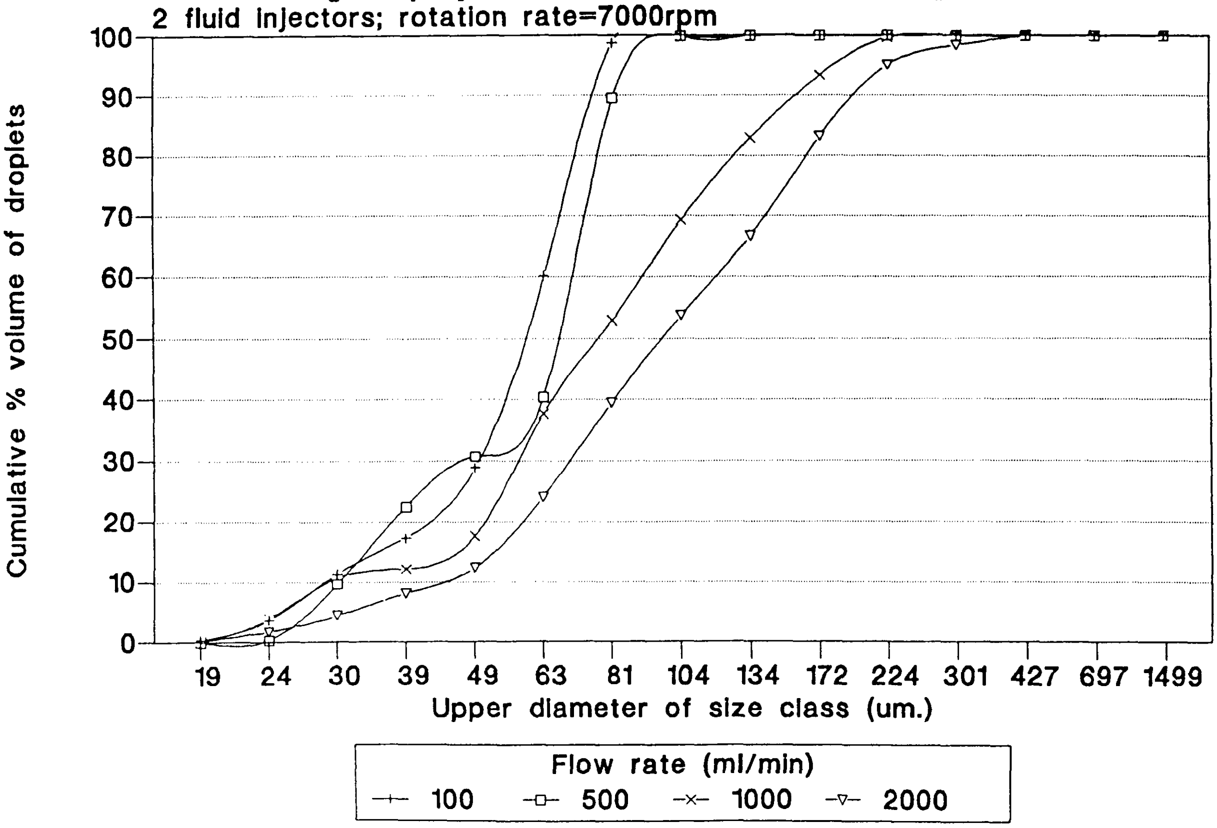


Fig 3.76 Cumulative percentage volume droplet distributions among size clas for water+Agral sprayed at different flow rates through Noric7 atomiser. 2 fluid injectors; rotation rate=7000rpm



measured parameters Q, N, U, σ, p, μ, D and m were transformed to logarithmic coordinates and regressed against the dependant parameter log VMD. Regressions were also carried out against the other measured dependant parameters: VAD, VMD/NMD ratio and VO (the percentage volume of the spray contained by droplets with diameter 40 to 100 μm).

STRAIGHT JET NOZZLES

Empirical models were developed for the straight jet air-shear nozzles relating all droplet size spectra parameters to the independant variables p, μ, Q and U. The independant variables σ and atomiser liquid issuing surface characteristics could not be accurately incorporated into the models.

Relatively large power indices were obtained for p and U (Table 3.2), indicating a strong correlation of droplet size spectra parameters with these variables. An increase in airstream velocity caused a large decrease in the VMD, VAD, VMD/NMD ratio and a large increase in the VO. An increase in viscosity caused moderate increases in the VMD, VAD, VMD/NMD ratio and a large decrease in the VO.

The independant variables showed the strongest correlation with VMD (r^2=0.94), giving rise to the following empirical model:

$$VMD \approx 9.6x10^{10}.Q^{0.97}.U^{-5.04}.\mu^{-0.59}.p^{2.40} \quad (r^2=0.94;\ df=230)$$

The power indices for the airstream velocity were higher than most previous studies with air-shear nozzles (Table 3.3). This is because most previous studies have involved industrial nozzles very different in design from those used on knapsack mistblowers. The author is not aware of the existence of other empirical models for predicting droplet size spectra produced by the type of air-shear nozzle used on knapsack mistblowers.

Table 3.2 Power indices for Straight jet air-shear nozzles.

Regression of VMD against p,μ,Q and U:

df=230; k=9.6e10; r^2=0.94; SE of y estimate=0.06

	p	μ	Q	U
Coefficient(s)	2.396	-.586	.097	-5.035
Std Err of Coef.	.264	.091	.014	.160

Regression of VAD against p,μ,Q and U:

df=230; k=80714582; r^2=0.87; SE of y estimate=0.06

	p	μ	Q	U
Coefficient(s)	1.737	-.017	.040	-3.140
Std Err of Coef.	.233	.008	.012	.141

Regression of VMD/NMD ratio against p,μ,Q,U and SAP:

df=230; k=2.1e8; r^2=0.92; SE of y estimate=0.07

	p	μ	Q	U
Coefficient(s)	1.677	-.579	.101	-4.420
Std Err of Coef.	.292	.101	.015	.177

Regression of VO against p,μ,Q and U:

df=230; k=1.412e-9; r^2=0.77; SE of y estimate=0.16

	p	μ	Q	U
Coefficient(s)	-4.026	.694	-.096	5.798
Std Err of Coef.	.635	.219	.033	.385

Table 3.3. Power indices of different empirical atomisation models.

Source	U	Q	D	N	σ	μ	ρ
	Independant variable						
Air-shear nozzles:							
Lorenzetto and Lefebvre (1977)	-1.00	1.93	-	-	0.33	-	-0.37
Jasuja (1982)	-0.90	0.80	-	-	0.45	0.80	-0.40
Present study	-5.04	0.10	-	-	2.40	-0.59	-
Spinning discs:							
Walton and Prewitt (1949)	-	-	-0.50	-1.00	0.50	-	-0.50
Oyama et al (1953)	-	0.20	-0.30	-1.00	-	-	-
Fraser et al (1957)	-	0.20	-0.20	-0.60	0.10	-0.10	-0.50
Ryley (1959)	-	0.19	-0.47	-1.41	-1.35	-1.48	-0.06
Fraser et al (1963)	-1.00	0.50	-0.25	-1.00	0.50	0.21	-
Dombrowski and Lloyd (1974)	-	0.33	-1.22	-1.32	-	-0.10	-
Kayano and Kamiya (1978)	-	0.32	-0.69	-0.79	0.26	0.65	-0.29
Tanasawa et al (1978)	-	0.10	-0.50	-1.00	0.50	-	-0.50
Frost (1981)	-	0.44	-0.80	-0.75	0.15	0.02	-0.16
Sanderson (1982)	-	0.18	-0.15	-0.58	-	-	-
Kinnersley (1987)	-	0.16	-0.72	-0.73	-	-	-
Hewitt (1991b)	-	0.18	-	-0.60	1.10	0.13	-
Present study (air-assisted)	-1.60	0.20	-	-0.40	-	-	-
Present study (no airstream)	-	0.58	-	-0.78	-	-	-

Table 3.3 (continued)

Source	Independant variable						
	U	Q	D	N	σ	μ	p .
Rotary cage atomisers:							
Parkin and Siddiqui (1990)	-0.16	0.17	-0.68	-0.49	-	-	-
Present study (N<5500)	-0.20	0.12	-	-0.31	-	-	-
Present study (N>5500)	-2.32	0.03	-	-0.40	1.62	0.26	-
Slotted rotary drums:							
Friedman et al (1952)	-	0.20	-0.20	-0.60	0.10	-0.20	-0.50
Herring and Marshall (1955)	-	0.24	-0.85	-0.82	-	-	-
Present study	-	0.19	-0.48	-0.47	-	-	-

Droplet sizes previously reported for motorised knapsack mistblower straight jet air-shear nozzles are generally within similar ranges to those predicted by the model developed in this study (Table 3.4). Most of these studies involved the use of magnesium oxide coated slides (May, 1950) for sizing droplets. The nozzles involved differed slightly in design from those evaluated in this study. These factors account for the observed differences in the measured and predicted VMD values.

Table 3.4. Comparison of predicted and measured droplet size spectra from air-shear mistblower nozzles.

Source	V	Q	Liquid	Measured VMD (μm)	Predicted VMD (μm)	Difference (%)
Anon						
(1979)	112	67	Risella	54	50	-7
""	83	950	Water	240	272	+13
Thornhill						
(1983)	90	1800	Water	200	193	-4
Thornhill						
(unpublished)						
	92	1600	kerosene	138	124	-10
""	""	300	""	124	105	-15

The Fontan twin liquid injector nozzle tended to produce larger VMD, VAD and VMD/NMD ratio values and a smaller VO than predicted by the empirical model whilst the Solo and Semco nozzles tended to produce similar or smaller VMD, VAD and VMD/NMD ratio values and a larger VO than predicted (Figs 3.77 to 3.80). These differences are due mainly to the effects of other independant variables not included in the model, including the relative position and orientation of the liquid injectors in the airstream. Liquid was released tangentially into the airstream with the Fontan and Semco nozzles and parallel with the airstream by the

Fig 3.77 Scatter plot of predicted VMD against measured VMD for knapsack mistblower straight jet air-shear nozzles.

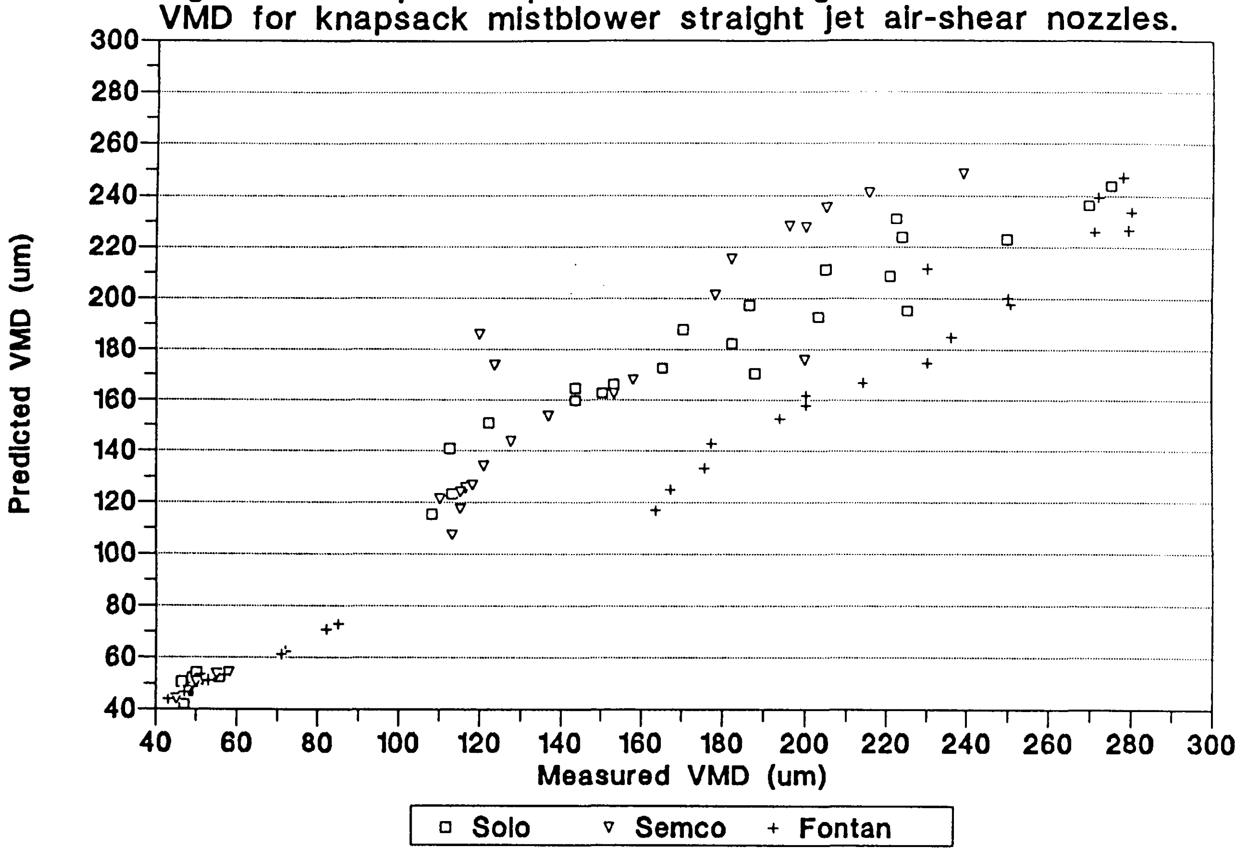


Fig 3.78 Scatter plot of predicted against measured VMD/NMD ratios for knapsack mistblower straight jet air-shear nozzles.

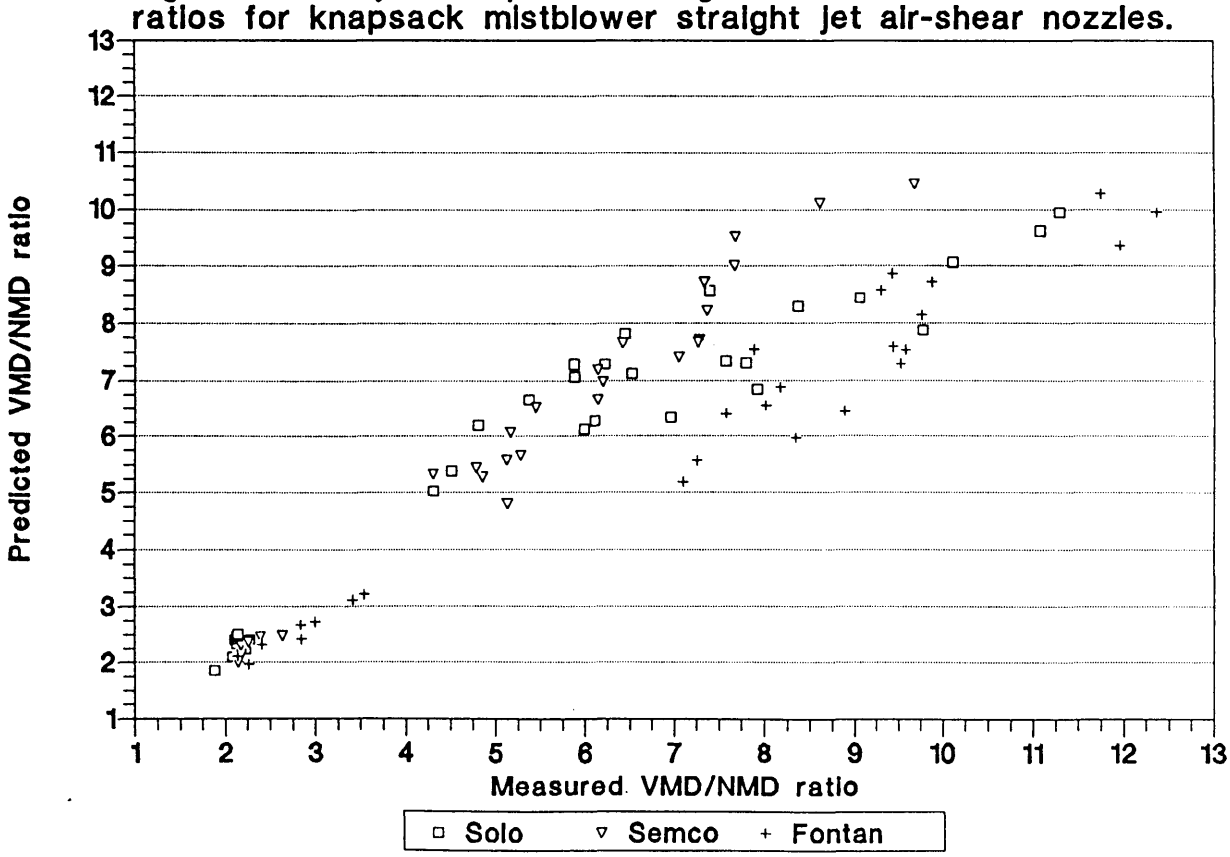


Fig 3.79 Scatter plot of predicted VAD against measured VAD for knapsack mistblower straight jet air-shear nozzles.

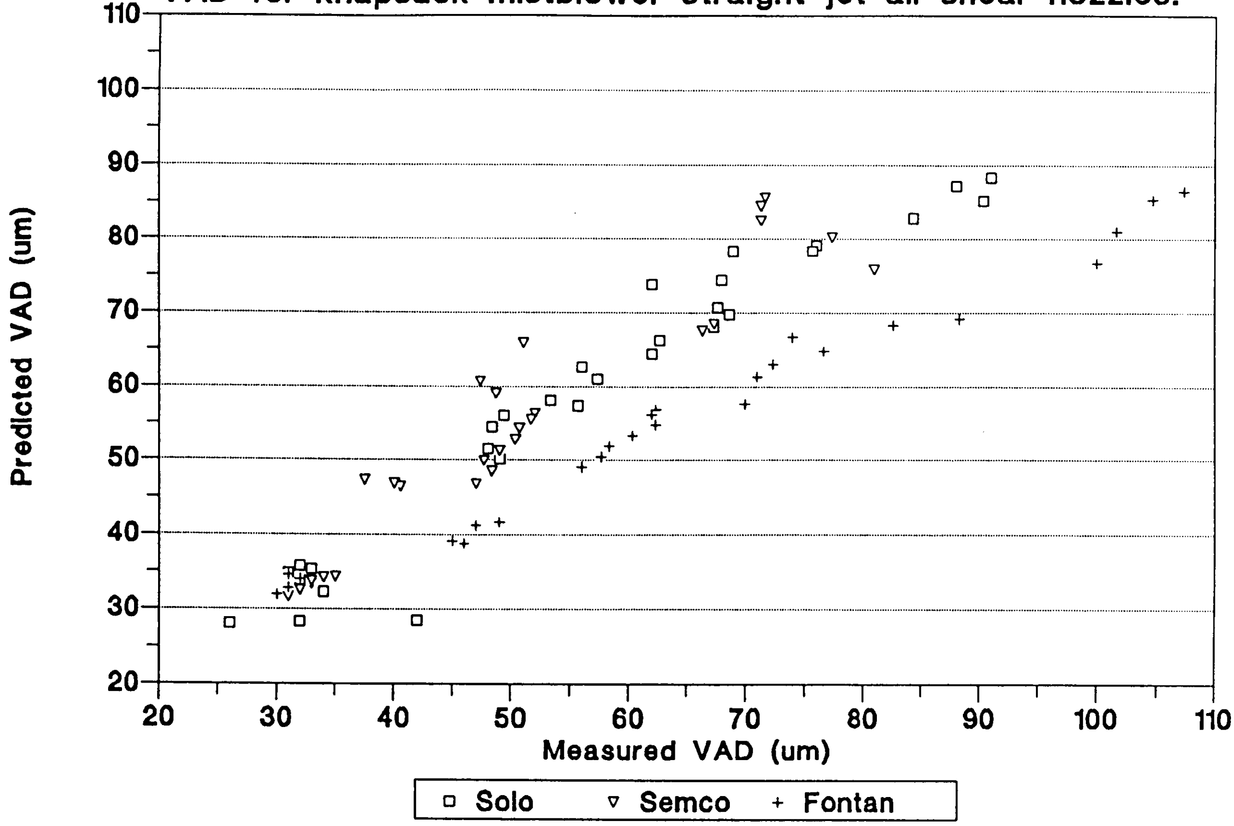
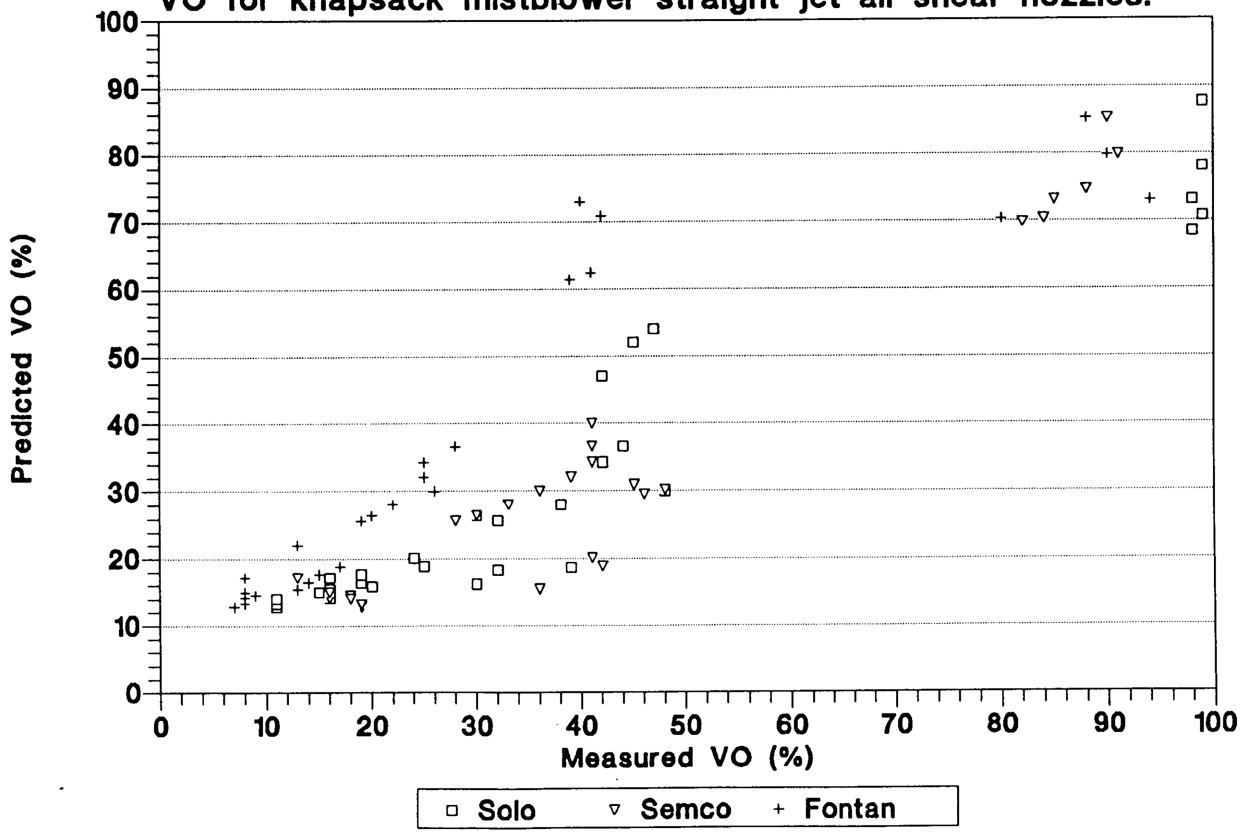


Fig 3.80 Scatter plot of predicted VO against measured VO for knapsack mistblower straight jet air-shear nozzles.



Solo nozzle. A comprehensive evaluation of the effect of every variable in straight jet air-shear nozzles was beyond the scope of this study.

CUPPED SPINNING DISC

The independant variables Q, N and U were incorporated into empirical models to predict VMD (r^2=0.94), VMD/NMD ratio (r^2=0.81) and VO (r^2=0.86) for the air-assisted X1 atomiser (Table 3.5) and to predict VMD (r^2=0.89) and VO (r^2=0.72) for the electrically-driven non air-assisted X1 atomiser (Table 3.6). SE values were between 0.01 and 0.64. Models could not be accurately developed relating Q, N and U to VAD for the air- and non-air assisted atomiser ($r^2 \leq 0.52$), or to predict VMD/NMD ratio for the non air-assisted X1 atomiser ($r^2 \leq 0.5$).

Table 3.5. Power indices for X1 atomiser operated with air-assistance.

Regression of VMD against Q,N and U:

df=82; k=1.8e6; r^2=0.94; SE of y estimate=0.05

	Q	N	U
Coefficient(s)	.198	-.404	-1.596
Std Err of Coef	.014	.026	.090

Regression of VMD/NMD ratio against Q,N and U:

df=82; k=158; r^2=0.87; SE of y estimate=0.14

	Q	N	U
Coefficient(s)	.117	-.263	-.635
Std Err of Coef.	.010	.019	.092

Regression of VO against Q,N and U:

df=82; k=1e-7; r^2=0.81; SE of y estimate=0.05

	Q	N	U
Coefficient(s)	-.309	.755	3.195
Std Err of Coef.	.041	.075	.261

Table 3.6. Power indices for X1 atomiser operated without air-assistance.

Regression of VMD against Q and N:

df=80; k=7215; r^2=0.89; SE of y estimate=0.11

	Q	N
Coefficient(s)	.576	-.775
Std Err of Coef.	.033	.099

Regression of VO against Q and N:

df=80; k=2.123e-8; r^2=0.72; SE of y estimate=0.7

	Q	N
Coefficient(s)	-2.023	3.365
Std Err of Coef.	.215	.642

The goodness of fit of the measured data to the empirical models can be seen in Figures 3.81 to 3.85.

The empirical models for VMD had the largest values of r^2, indicating relatively strong correlation between VMD and the independant parameters. The empirical model to predict the VMD for the non air-assisted X1 atomiser was as follows:

$$VMD \approx 7215.Q^{0.58}.N^{-0.78}$$

(r^2=0.89; df=80)

The power indices given in this model were similar to those obtained by Frost (1981) who derived values of 0.44 for Q and -0.75 for N for non air-assisted spinning disc atomisers.

With the addition of external air-assistance with velocity between 77 and 116 m/sec from motorised knapsack mistblowers, the dependance of VMD upon Q and N decreased as U became very important, as shown in the following empirical model:

$$VMD \approx 1.8x10^{6}.Q^{0.2}.N^{-0.4}.U^{-1.6}$$

(r^2=0.94; df=82)

These values suggest that U has a greater, and Q and N have lower effects upon VMD than suggested by Fraser et al

Fig 3.81 Scatter plot of measured and predicted VMD for X1 atomiser operated with air-assistance.

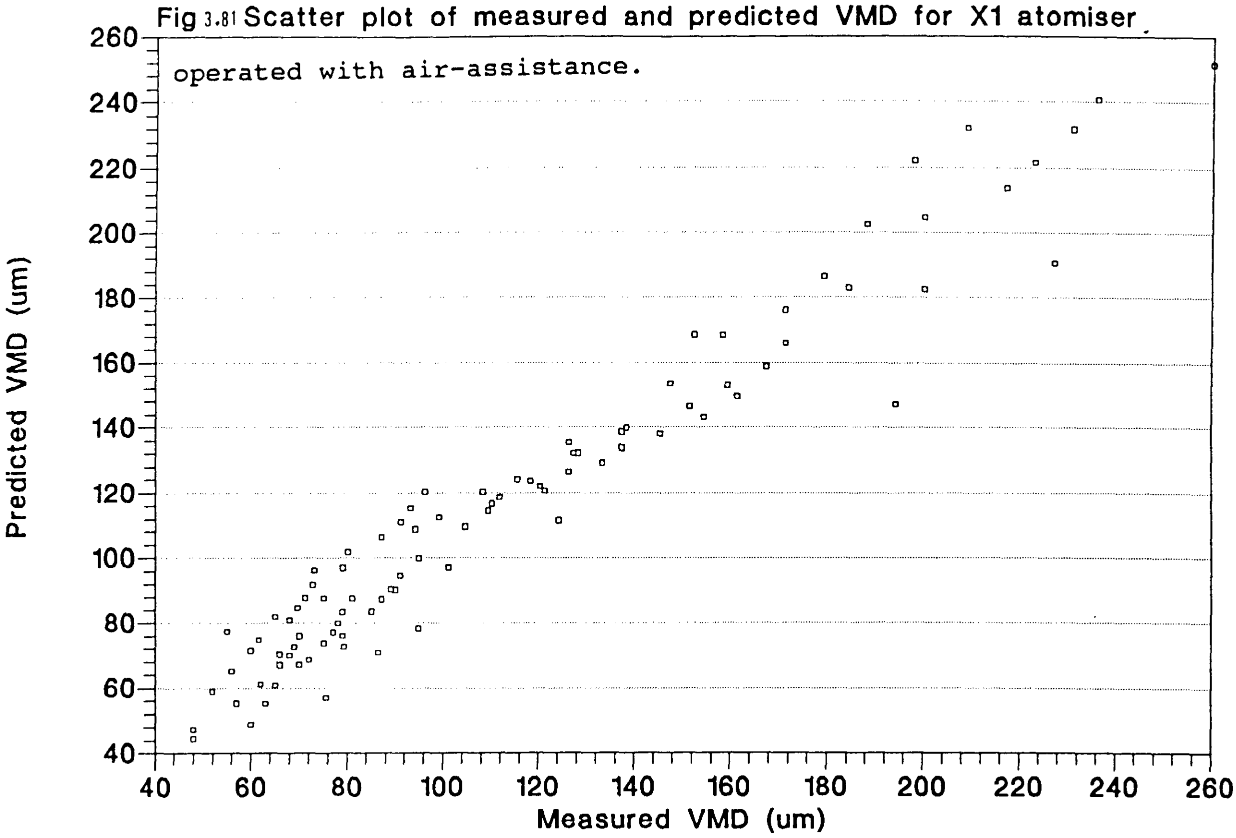


Fig 3.82 Scatter plot of measured and predicted VMD/NMD ratio for X1 operated with air-assistance.

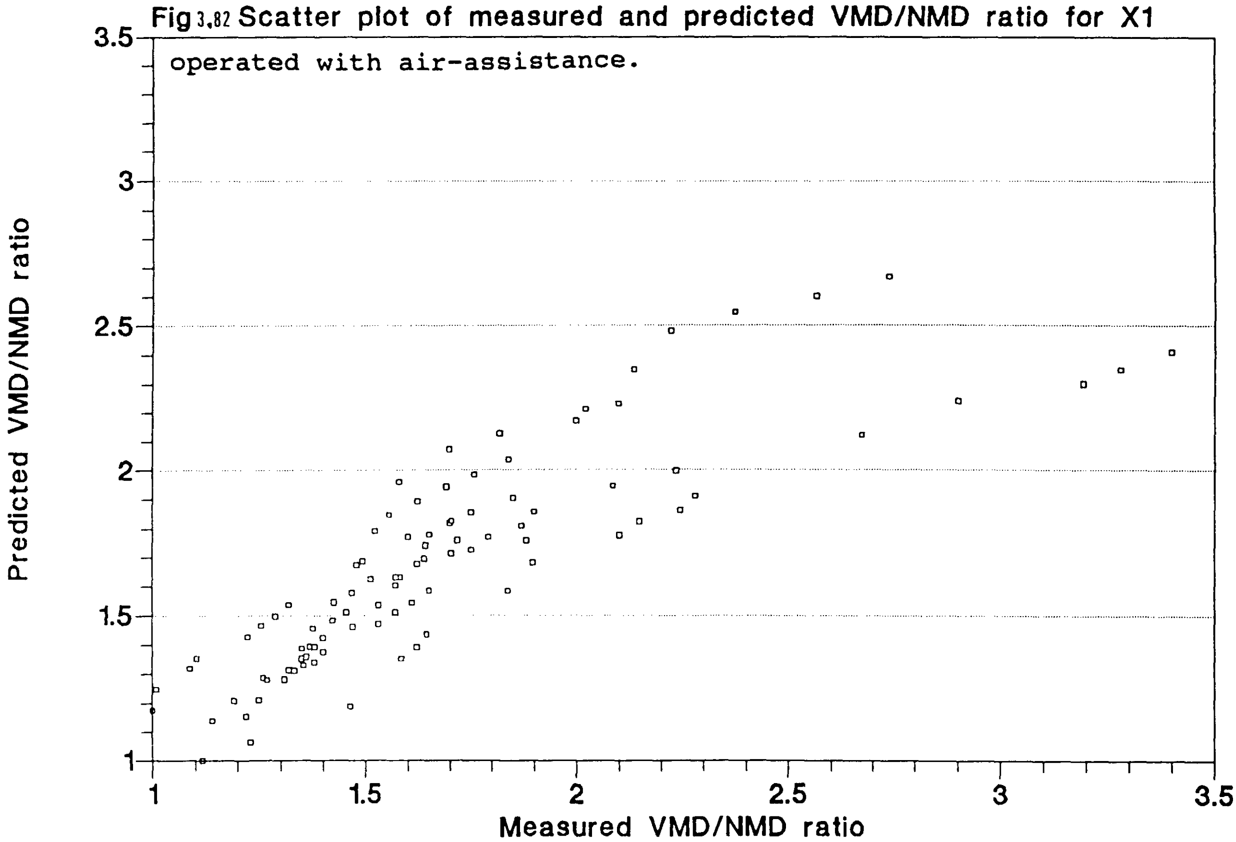


Fig 3.83 Scatter plot of measured and predicted VO for X1 atomiser operated with air-assistance.

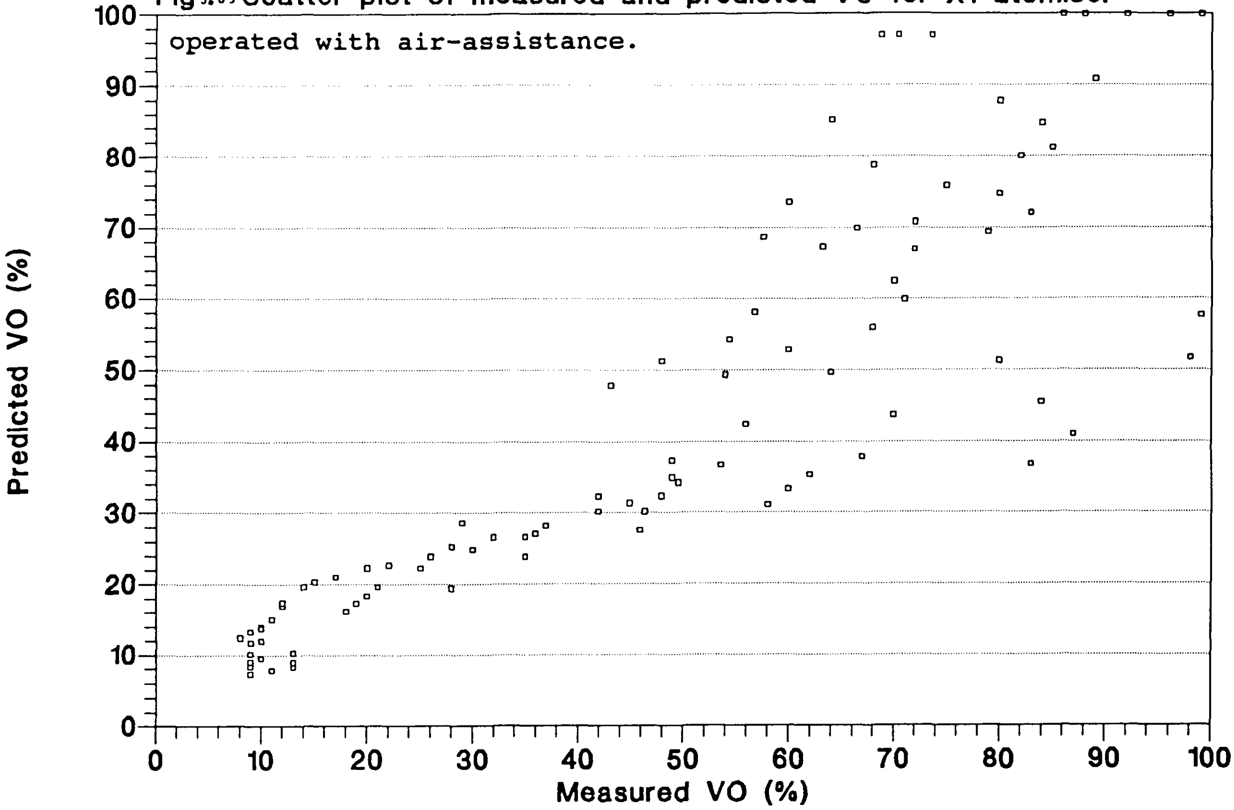


Fig 3.84 Scatter plot of measured and predicted VMD for X1 atomiser operated without air-assistance.

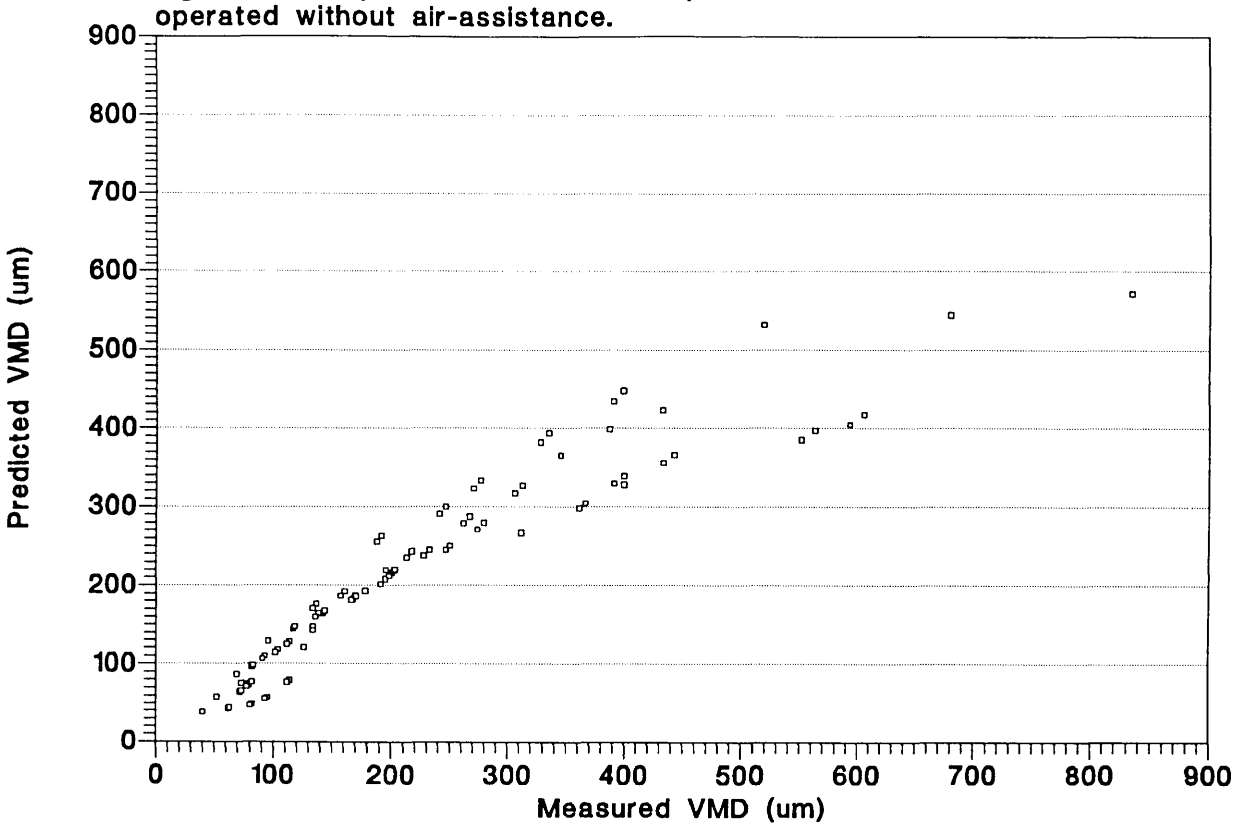
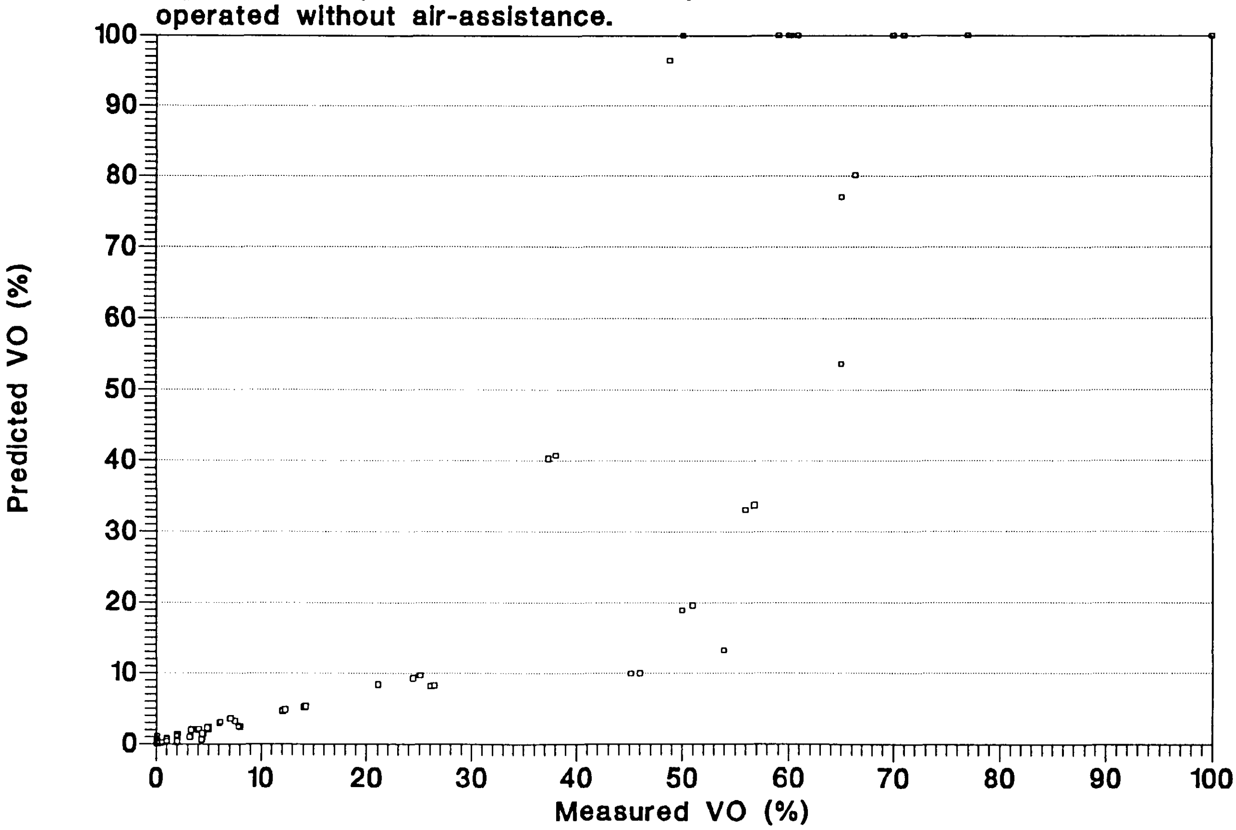


Fig 3.85 Scatter plot of measured and predicted VO for X1 atomiser operated without air-assistance.



(1963) who obtained power indices of 0.5, -1.0 and -1.0 respectively for Q, N and U. This difference is due to differences in experimental procedure, in the ranges of Q,N and U involved in the studies, in liquid type and in atomiser design.

ROTARY CAGE ATOMISER

The AU8000 droplet size spectra could not be accurately expressed by single empirical models for each dependant variable. This was because there was a change in the mode of droplet formation as N and U increased. Models were developed for two rotation rate and airstream velocity regimes as follows:

<u>1. 13000 ≥ N ≥ 5500 rpm, and 116 ≥ U ≥ 87 m/sec.</u>

The independant variables Q, N, U, μ and σ were incorporated into models with SE values between 0.009 and 0.437 for the calculated power indices (Table 3.7).

Table 3.7 Multiple linear regression for AU8000 where N>5500:

Regression of VMD against Q,N,U,μ, and σ:

df=690; k=3.1e10; r^2=0.94; SE of y estimate=0.05

	Q	N	U	μ	σ
Coefficient(s)	.027	-.399	-2.320	.258	1.619
Std Err of Coef.	.009	.033	.096	.012	.076

Regression of VAD against Q,N,U,μ and σ:

df=690; k=3.8; r^2=0.86; SE of y estimate=0.07

	Q	N	U	μ	σ
Coefficient(s)	.026	-.488	-1.885	.227	1.639
Std Err of Coef.	.014	.054	.156	.020	.124

Regression of VO against Q,N,U,μ,σ and p:

df=690; k=5.7e-11; r^2=0.70; SE of y estimate=0.18

	Q	N	U	μ	σ	p
Coefficient(s)	-.083	.114	4.810	-.203	-1.365	-1.287
Std Err of Coef.	.033	.124	.360	.047	.286	.437

The variable m could not be accurately incorporated into the models. Parkin and Siddiqui (1990) also could not accurately incorporate the effects of cage mesh size into empirical models developed for predicting the VMD of water-based sprays atomised by larger Micronair AU3000 rotary cage atomisers.

Liquid density could not be accurately incorporated into the VMD and VAD models, but showed a strong negative correlation with VO.

An accurate model for VMD/NMD ratio could not be developed because it showed relatively poor correlation with the independant variables ($r^2 \leq 0.3$). This was because there were large variations in the number of relatively small satellite droplets produced by the different liquids under different regimes of Q, N and U. The NMD and therefore the VMD/NMD ratio is very sensitive to changes in the number of satellite droplets in a spray.

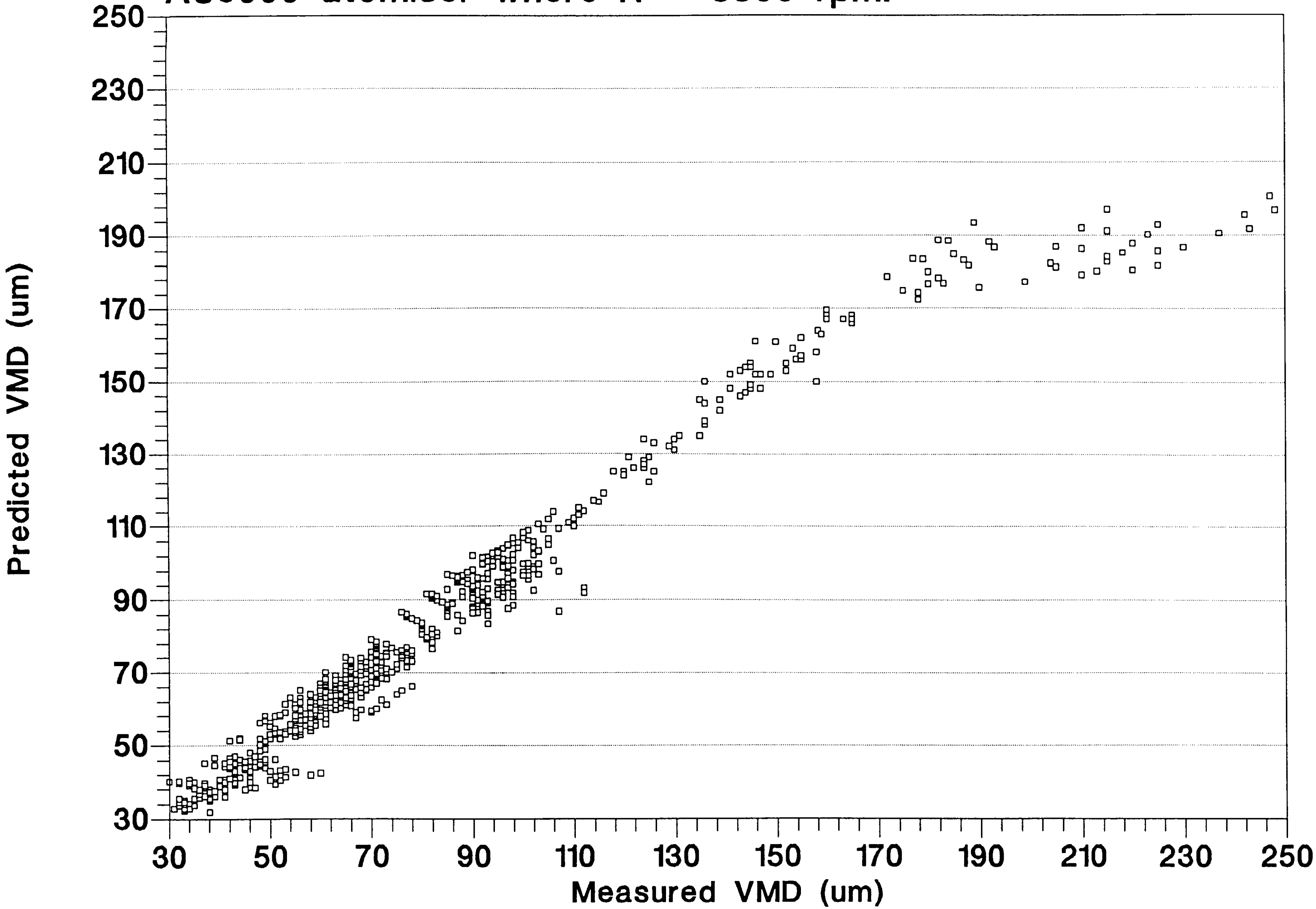
The empirical model for VMD had the largest value of r^2 (0.94), indicating a relatively high degree of correlation between the dependant and independant parameters. The empirical model to predict the VMD was as follows:

$$VMD \approx 3.1x10^{10}.Q^{0.03}.N^{-0.4}.U^{-2.32}.\mu^{0.26}.\sigma^{1.62}$$

($r^2=0.94$; df=690)

The fit of the measured VMD values to this model can be seen in Fig 3.86. The underestimation of VMD values above

Fig 3.86 Scatter plot of measured and predicted VMD for AU8000 atomiser where N > 5500 rpm.



200 μm was due mainly to a change in the mode of droplet formation.

The other dependant variables generally showed lower overall correlations with the independant variables when analysed with multiple linear regression with two main exceptions. The VAD showed the largest correlation with N (power index = -0.49) and the VO showed a very large degree of correlation with U (power index = 4.81).

The power index of 0.03 obtained for Q where N > 5500 rpm was very low compared to previous studies with rotary atomisers (Table 3.3). This indicates that VMD changed very little with variations in flow rate. The larger Micronair AU3000 series of atomisers studied by Parkin and Siddiqui (1990) showed a stronger dependance of VMD upon Q because higher flow rates were invloved (2000 to 10000 ml/min, compared to 50 to 2000 ml/min in this study).

<u>2. 5500 > N > 50 rpm and 116 ≥ U ≥ 0 m/sec.</u>

The empirical models developed for AU8000 rotation rates between 50 and 5499 rpm (Table 3.8) had lower r^2 and higher SE values than the similar models for higher rotation rates described above, so were less accurate than the higher rotation rate and air velocity models.

Table 3.8 Multiple linear regression for AU8000 where N<5500:

Regression of VMD against Q,N and U:

df=192; k=1307; r^2=0.74; SE of y estimate=0.2

	Q	N	U
Coefficient(s)	.124	-.311	-.196
Std Err of Coef.	.084	.045	.017

Models could not accurately be developed for VAD ($r^2 \leq 0.56$), VMD/NMD ratio ($r^2 \leq 0.19$) and VO ($r^2 \leq 0.54$). The goodness of fit of the measured data to the VMD and VMD/NMD ratio models can be seen in Figures 3.87 and 3.88.

Mesh size, liquid viscosity and density could not be accurately incorporated into the models. Rotation rate had the largest effect upon the VMD, as shown by the following empirical equation:

$$VMD \approx 1.3 \times 10^3 . Q^{0.12} . N^{-0.31} . U^{-0.20} \qquad (r^2=0.74;\ df=192).$$

Fig 3.87 Scatter plot of measured and predicted VMD for AU8000 atomiser where N < 5500 rpm.

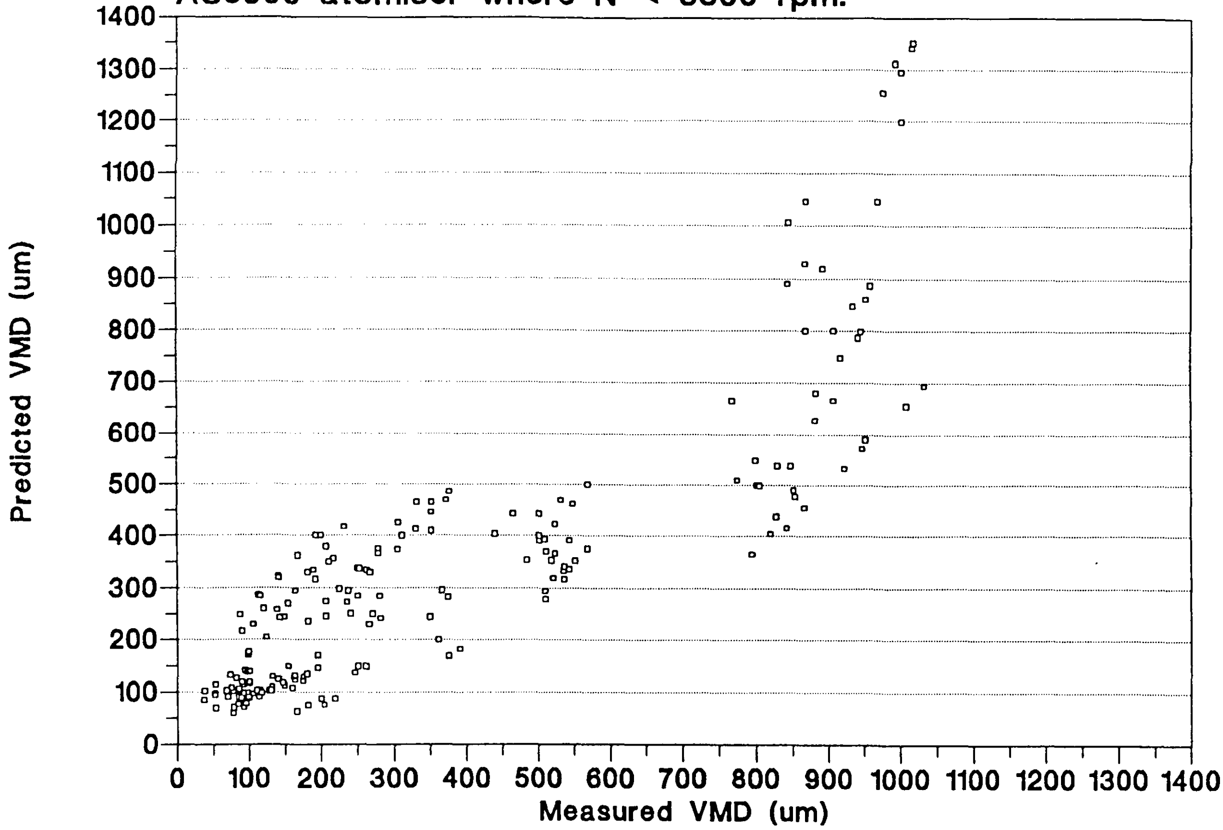
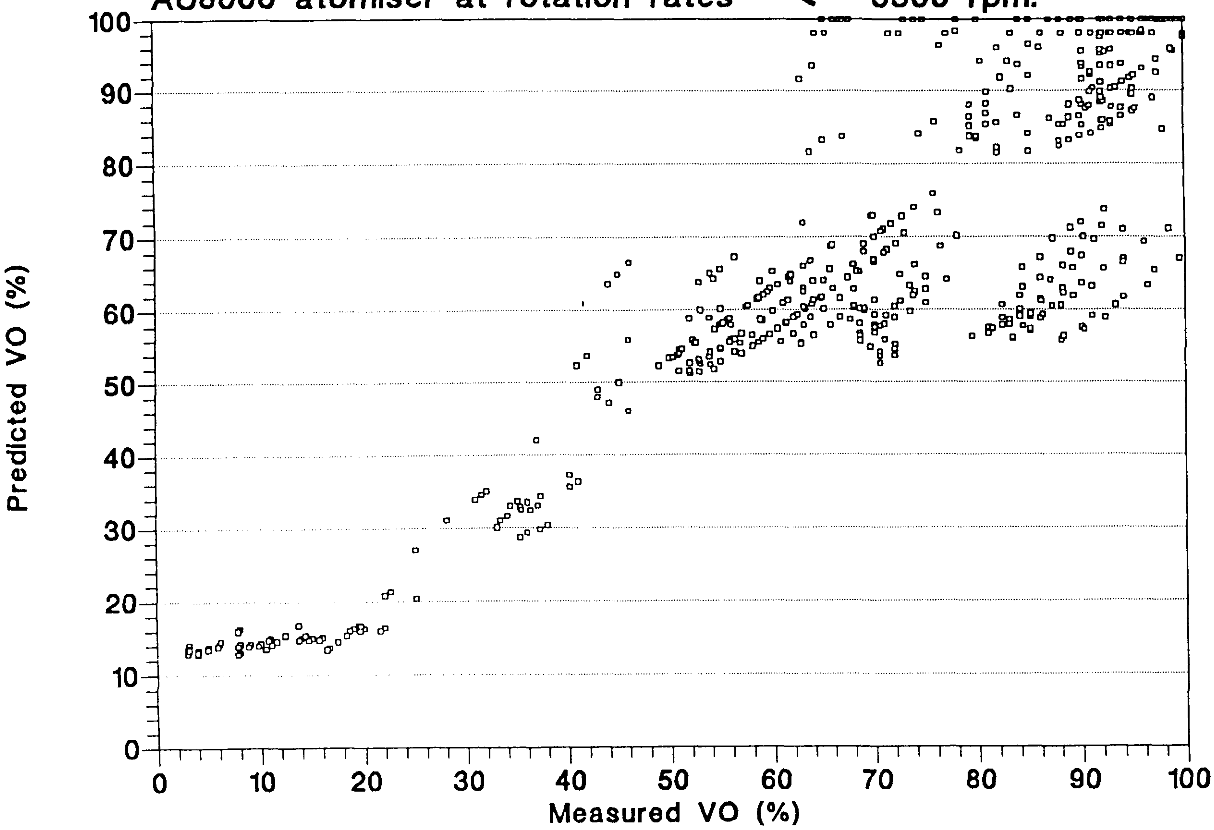


Fig 3.88 Scatter plot of measured and predicted VO for AU8000 atomiser at rotation rates < 5500 rpm.



When operated at rotation rates below 5500 rpm, the VMD produced by the AU8000 atomiser was less dependant upon U and N but more dependant upon Q than with operation at higher rotation rates. The power indices observed with N below 5500 rpm were similar to those derived for rotary cage atomisers by Parkin and Siddiqui (1990) who suggested that droplet formation was occuring predominantly by ligament disintegration with some jet-on-wire shatter as discussed by van Vliet and Picot (1987).

SLOTTED ROTARY DRUMS

Empirical models developed for the slotted rotary drum atomisers rotating in the same direction as the vanes showed there was fairly strong correlation of Q, N and D with VMD (r^2=0.9), VAD (r^2=0.9), VMD/NMD ratio (r^2=0.87) and VO (r^2=0.71). VMD, VAD and VMD/NMD ratio showed positive correlation with Q and D and negative correlation with N. The reverse effect was observed for VO. The empirical model for VMD was as follows:

$$VMD \approx 386.Q^{0.19}.N^{-0.47}.D^{-0.48} \quad (r^2=0.90;\ df=228)$$

where D is drum external diameter (m). The goodness of fit of the measured data to each model is shown on Figs 3.89 to 3.92.

The rotary atomiser power indices for Q, D and N obtained for the slotted rotary drum atomisers (Table 3.9) were

Table 3.9 Power indices for Noric slotted rotary drum atomisers.

Regression of VMD against Q, N and D:

df=228; k=386; r^2=0.90; SE of y estimate=0.04

	Q	N	D
Coefficient(s)	.186	-.473	.478
Std Err of Coef.	.012	.059	.269

Regression of VAD against Q, N and D:

df=228; k=0.025; r^2=0.90; SE of y estimate=0.02

	Q	N	D
Coefficient(s)	.039	-.430	.459
Std Err of Coef.	.006	.029	.131

Regression of VMD/NMD ratio against Q, N and D:

df=228; k=4.8e-8; r^2=0.87; SE of y estimate=0.05

	Q	N	D
Coefficient(s)	.284	-.441	.391
Std Err of Coef.	.017	.081	.370

Regression of VO against Q, N and D:

df=228; k=2.76e7; r^2=0.71; SE of y estimate=0.07

	Q	N	D
Coefficient(s)	-.196	.666	-.873
Std Err of Coef.	.023	.111	.507

Fig 3.89 Scatter plot of measured and predicted VMD for Noric slotted rotary drum atomisers.

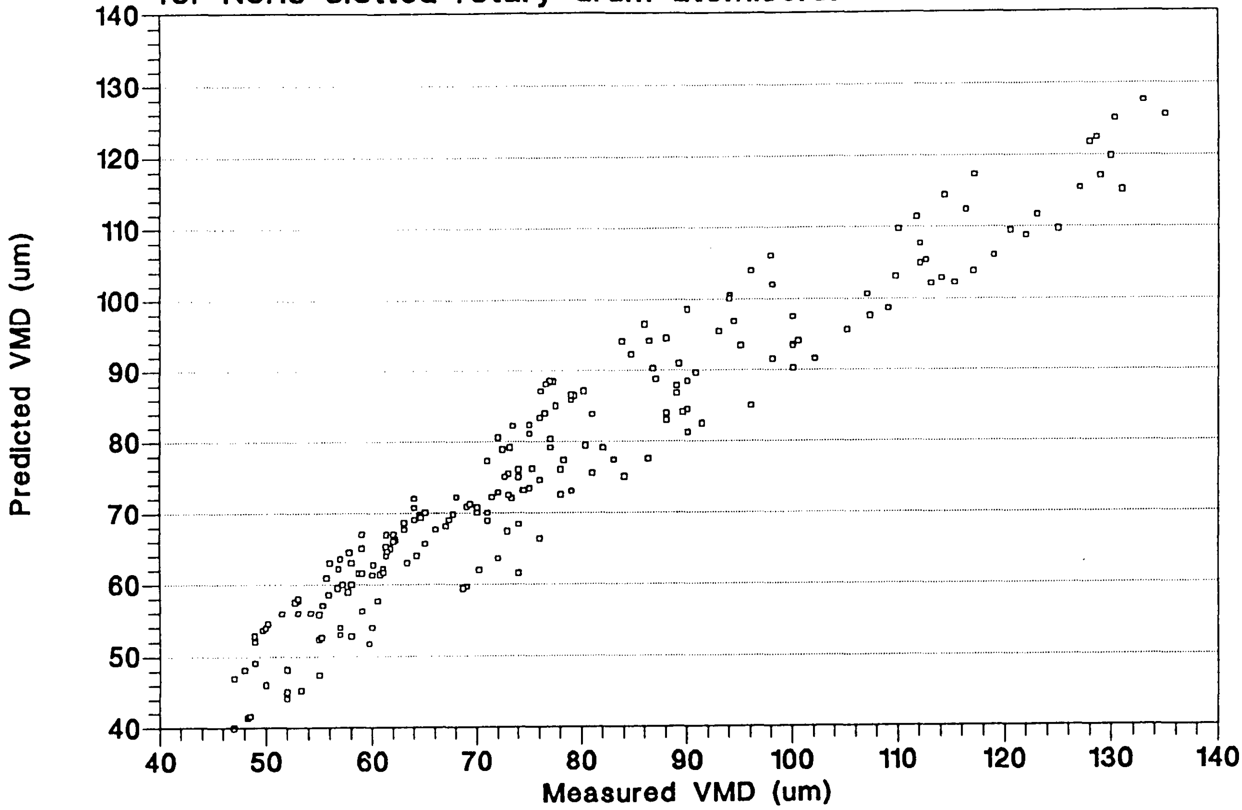


Fig 3.90 Scatter plot of measured and predicted VAD for Noric slotted rotary drum atomisers.

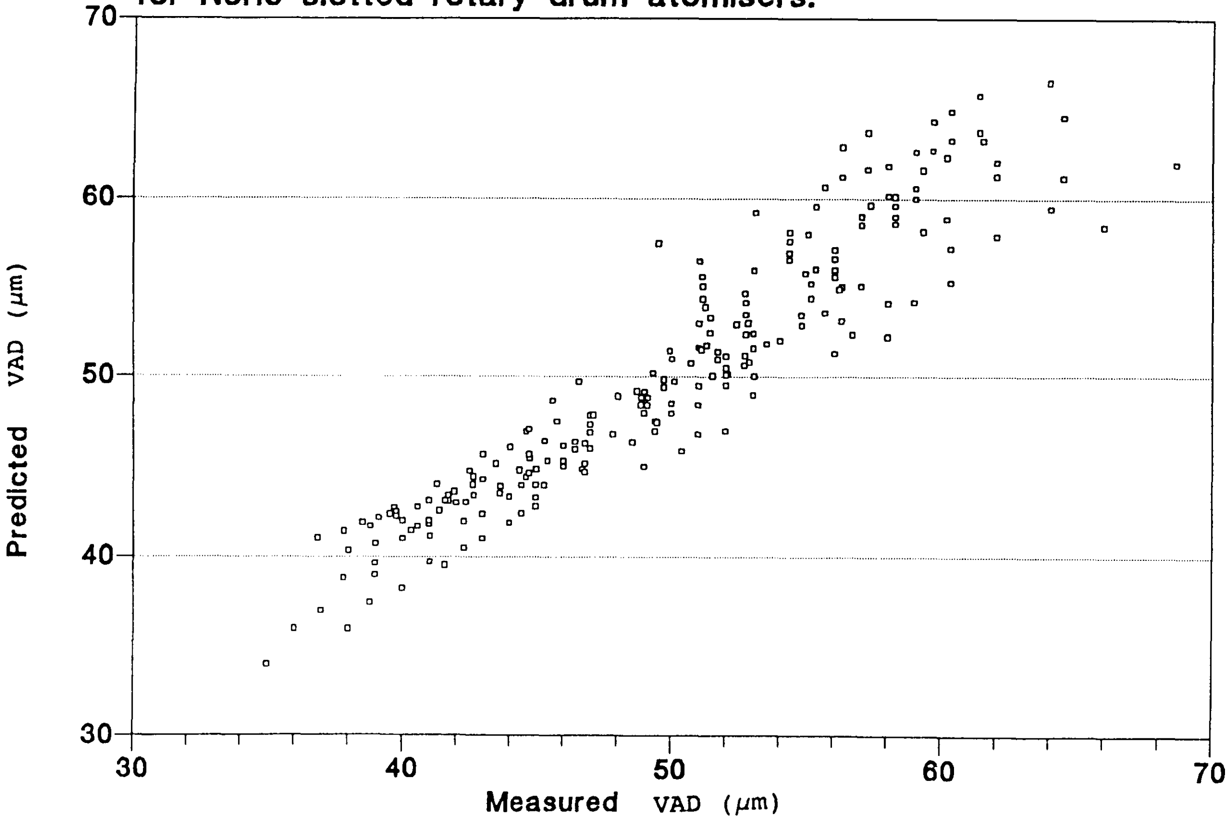


Fig 3.91 Scatter plot of measured and predicted VMD/NMD ratio for Noric slotted rotary drum atomisers.

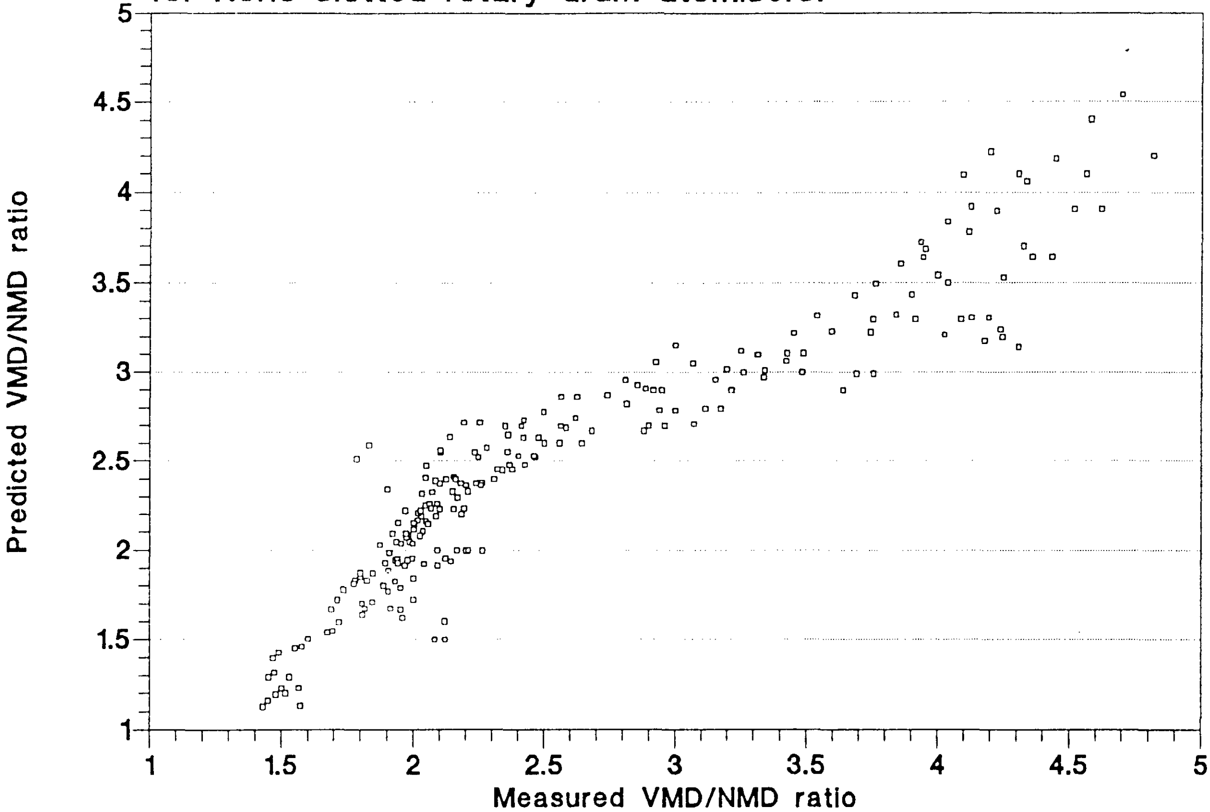
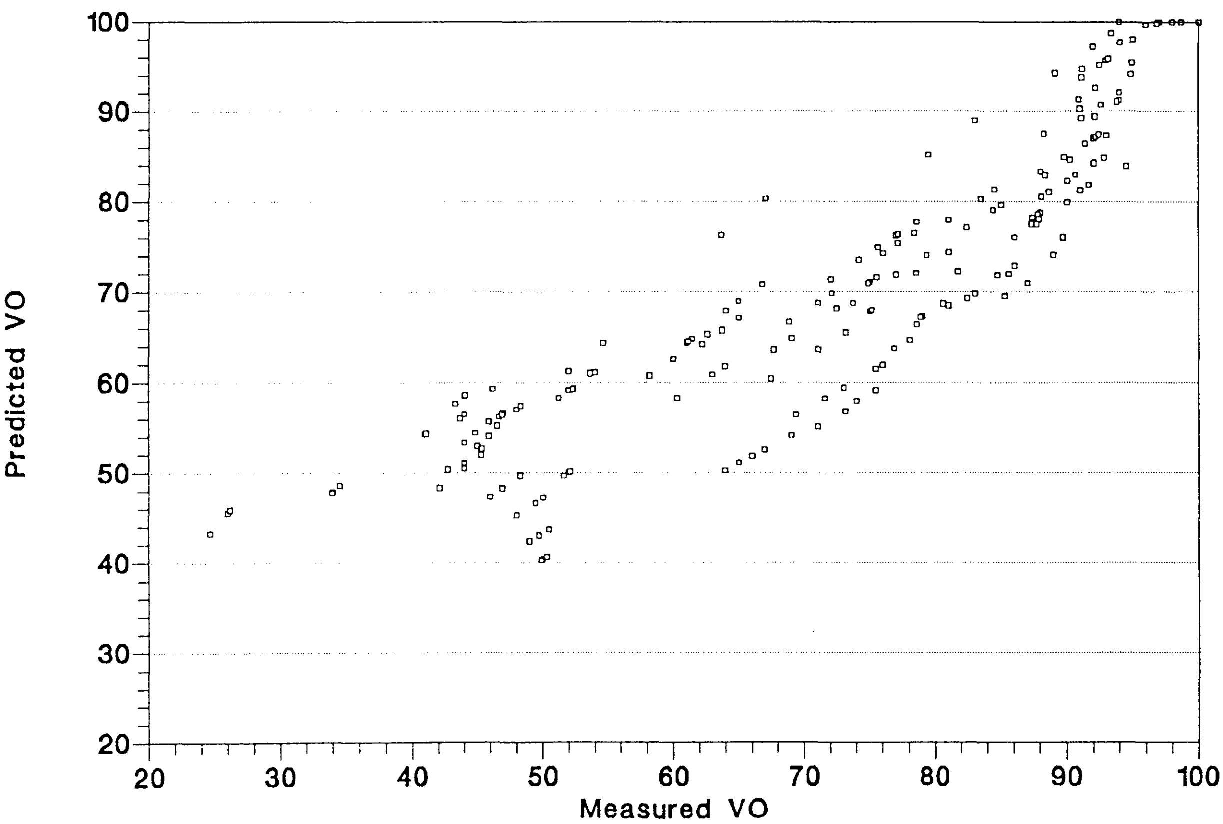


Fig 3.92 Scatter plot of measured and predicted VO for Noric atomisers.



within similar ranges to those produced by most previous studies with slotted rotary atomisers (Table 3.3). The variation in values between workers is due to differences in drum design, liquid distribution system and experimental procedure, especially the droplet sizing technique.

The power indices also showed close aggreement with those derived by Parkin and Siddiqui (1990) for rotary cage atomisers.

3.3.2. LIQUID TYPE

Although this study did not compare droplet size spectra produced by liquids with a wide range of physical properties, the comparative results for the three liquids involved agreed broadly with many previous studies.

Ford and Furmidge (1967), Haq and Rahman (1979) and Lefebvre (1989) suggested that surface tension had a particularly important effect upon droplet size spectra. The relatively high positive power index obtained in this study for surface tension showed that an increase in surface tension gave rise to a large increase in droplet size. Surface tension is important since it resists atomisation and must be overcome by an input of energy before individual droplets will form from the bulk liquid.

The relatively low effect of liquid viscosity upon droplet size spectra agrees with Simmons (1979) who obtained a low power index of 0.06 for dynamic viscosity compared to 0.375 for surface tension with a range of air-assisted atomisers.

Liquid density could not be accurately incorporated into empricial models to predict the droplet size spectra parameters because density has relatively little effect upon droplet size compared to viscosity and surface tension (Lefebvre, 1989).

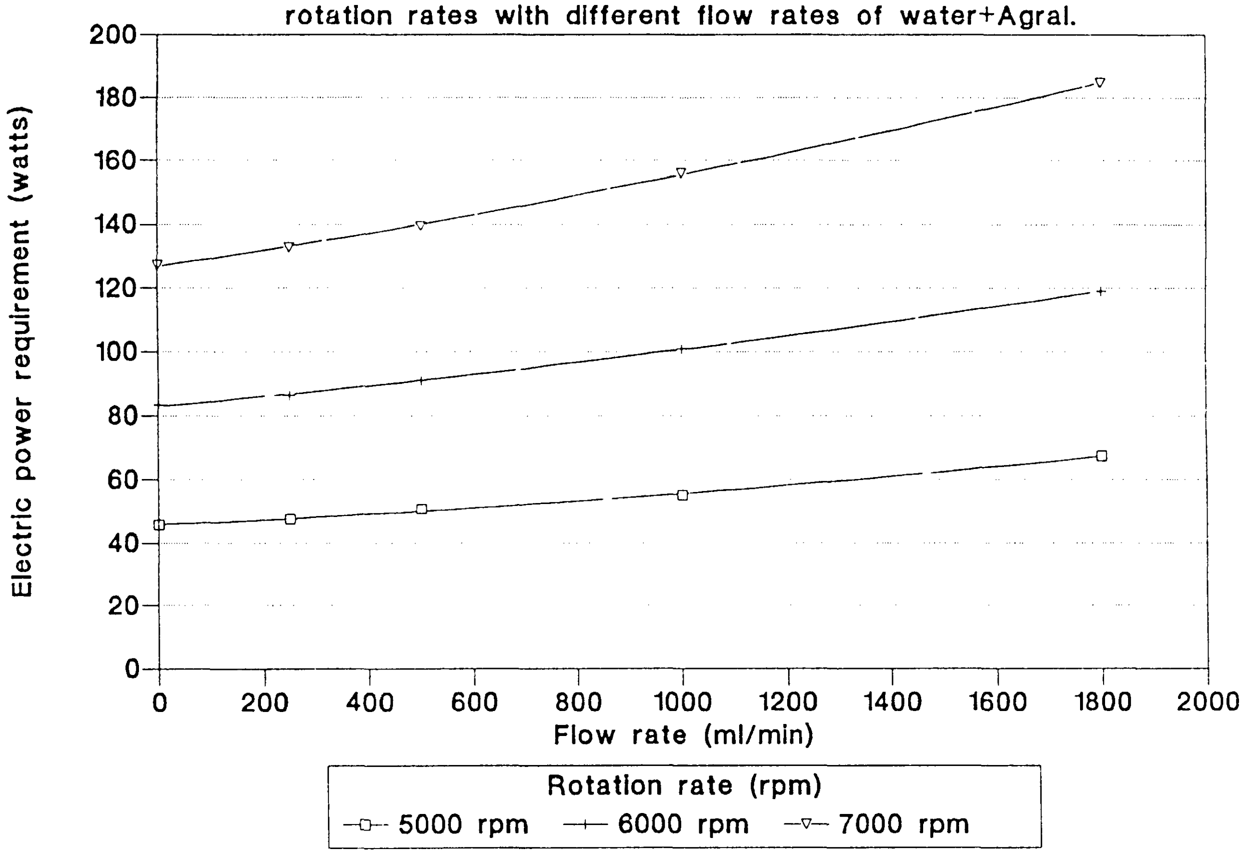
The wide range of power indices observed between different workers is due mainly to differences in the range of physical properties studied. The liquids involved in this study had physical properties within ranges commonly encountered in pesticide formulations. Many previous studies have involved liquids used for different purposes including combustion and spray drying.

3.3.3. LIQUID FLOW RATE AND ATOMISER ROTATION RATE

The difference in the rotation rate of depression with different liquids was due to differences in the physical properties of those liquids. The relatively low rates of depression observed for kerosene and Risella were probably due to their relatively low densities of 0.783 and 0.875 kg/l compared to 1.0 kg/l for water. The higher density of water would cause increased rates of drag upon the rotating surfaces. The relatively high viscosity of Risella (32.4 cP) compared to kerosene (1.78 cP) did not cause a large difference in loaded rotation rates between these liquids.

The rise in the rate of rotation decrease with higher atomiser rotation rate was probably due mainly to an increase in energy required to obtain higher speeds. This is exemplified by the electric-driven NORIC drums where the rate of power required increased with increasing rotation rate (Fig 3.93).

Fig 3.93 Power requirement of NORIC 7 for different clockwise rotation rates with different flow rates of water+Agral.



The increase in VMD, VAD and VMD/NMD ratio with higher flow rate, due to an increase in the length and width of jets, ligaments and sheets of liquid leaving the atomiser peripheries, agreed with the findings of most previous studies on straight jet air-shear atomisation (Jasuja, 1982; Lorenzetto and Lefebvre, 1977; Weber, 1931) and rotary atomisation (Fraser et al, 1957; Frost, 1981; Parkin and Siddiqui, 1990). The bi- and tri-modal spectra observed from all atomisers at particular flow and rotation rates were due to the formation of satellite droplets as described by Dombrowski and Lloyd (1974).

The decrease in VMD and VAD with higher rotation rate at a given flow rate was due to droplet formation occuring in the ligament mode over a wider range of flow rates as described by Boize and Dombrowski (1976). found that an increase in atomiser rotation rate caused a decrease in the flow rate where transition occurred from direct drop to ligament formation and an increase in the transitionary flow rate for ligament to sheet formation. This study showed that an increase in drum rotation rate caused a decrease in the VMD and a decrease in the droplet spectrum width. In agreement with the observations of Boize and Dombrowski (1976), the flow rate range where ligament formation occurred increased with increasing drum rotation rate. The higher rotational rates allowed the viscous and surface tension forces resisting atomisation to be more readily overcome (Fraser et al, 1963) producing ligaments with reduced length and width which in turn gave rise to smaller droplets breaking off closer to the periphery of the atomisers.

3.3.4. LIQUID DISTRIBUTION AT ATOMISER PERIPHERY

ATOMISER PERIPHERAL SURFACE AREA

The reduction in the VMD and VMD/NMD ratio observed with the rotary atomisers was due partly to the increased peripheral surface area across which the liquid was spread before atomisation.

Dombrowski and Munday (1968) noted that the most effective way of utilizing energy imparted to a liquid is to arrange that the liquid has a large specific surface before it commences to break- down into drops. Several previous workers have observed that mean drop diameter is approximately proportional to the square root of the liquid film thickness (Hagerty and Shea, 1955; York, 1953). The rotary atomisers effectively transposed the bulk liquid into thin sheets, ligaments and finally drops, thereby achieving a narrower droplet spectrum than the straight jet air-shear system where the atomisation occured from a smaller specific surface.

LIQUID DELIVERY TO PERIPHERAL SURFACE

It is likely that liquid issues from a relatively narrow section of the peripheral guaze on rotary cage atomisers (R. Kinnersley, personal communication). There was some evidence of this effect when liquid was observed leaving the AU8000 atomiser with stroboscopic illumination. At very low rates of liquid flow, liquid tended to leave the drum section nearest the blades. As flow rate increased, liquid issued from the entire guaze.

Diffusers should facilitate the delivery of a more even liquid column to the guaze and reduce the pulsations of liquid flow generally associated with rotary cage atomisers and observed during operation of the AU8000 in the laboratory and field. The diffuser design currently used in AU8000 atomisers (referred to as diffuser 1 in this study) produced lower VMD values than the other designs tested because it probably gave a more even distribution of liquid across the peripheral guaze of the atomiser, leading to uniform atomisation across a larger surface area than with the other diffuser designs.

The increasing variation in the VMD and VMD/NMD ratios produced by different slotted rotary drum liquid injector orientations relative to the laser beam with increasing liquid flow rate was probably due to uneven liquid distribution across the drum periphery. At flow rates up to 500 ml/min, observations under stroboscopic illumination showed that although liquid distribution across the vanes was uneven, no vanes received sufficient liquid flow to cause sheet formation. Atomisation was by ligament and direct drop formation. As flow rate increased to 1000 and 1800 ml/min, the drum vanes nearest to the injector became flooded with liquid. Atomisation from these vanes was by sheet disintegration, giving rise to larger droplets. The drum vanes furthest from the injector received liquid at a lower rate. Atomisation from these vanes was by ligament disintegration. Liquid does not instantaneously leave the drum after being pumped to the vanes, but will be delayed as it flows across the vanes to the drum periphery. When the injector was at 180^{o} to the laser beam, a relatively large proportion of the droplets formed by sheet disintegration were probably sampled through the shroud window. This would give rise to the relatively large VMD and VMD/NMD ratios observed at this position. Conversely, with the injector at 0^{o} to the laser beam, most droplets being sampled were probably those formed by ligament and direct droplet formation.

If a spray cloud with a relatively small VMD and VMD/NMD ratio is required from a drum with a single liquid injector at flow rates above 500 ml/min, the drum should be shrouded at the injector side. Shrouds have previously been used to regulate swath widths, as with the Herbaflex system where liquid is collected by the shroud and re-circulated to feed the atomiser again. In tunnel sprayers, this could be included as part of the liquid re-circulation process to avoid the wastage of liquid.

3.3.5. AIRSTREAM VELOCITY

In agreement with many previous studies (Aigner and Wittig, 1985; Fraser <u>et al</u>, 1963; Lefebvre, 1989), airstream velocity was generally the most important factor affecting the droplet size produced by the air-assisted rotary atomisers. An increase in air volume also tends to cause a decrease droplet size due to the higher momentum exchange (Aigner and Wittig, 1985). The importance of ensuring that the liquid is released in the highest possible air velocity (Lefebvre, 1989) is evident.

The dependance of droplet size spectra parameters upon airstream velcoity was reduced from a power of approximately -5 to -2 by releasing the liquid from a rotating rather than a static surface. When the liquid was spread across the increased surface area provided by the AU8000 guaze rotating at rates below 5500 rpm, the dependance of droplet size upon U further decreased to ~0.2.

The addition of an external airstream to the rotating X1 and AU8000 atomisers allowed atomisation to be achieved in the ligament mode of droplet formation at increased liquid flow rates, producing spray with a relatively low VMD and VMD/NMD ratio, and a higher VO value. At higher airstream velocities, ligament length and width from the atomisers decreased as droplets were more rapidly sheared from ligaments, causing a decrease in droplet size. The phenomenom of decreased VMD with a higher airstream velocity agrees with the observations of Castleman (1932) and Lorenzetto and Lefebvre (1977) for air-shear nozzles; Fraser et al (1963) and Spillman and Sanderson (1982) for spinning disc atomisers; Parkin and Siddiqui (1990) for rotary cage atomisers; and Rokicki and Wills (1987) for a slotted rotary drum atomiser.

3.3.6. SLOTTED ROTARY DRUM ATOMISER DESIGN

The relatively small differences in the VMD and VMD/NMD ratio values observed when drums 1 and 4 were rotated in different directions were probably due mainly to the relatively large angle of the vanes to the drum shaft (74^{o}). Inspections with stroboscopic light showed that most of the liquid fed to these vanes did not travel across the entire vane surface but tended to impact with the outer vane rims where atomisation occurred.

Observations of drums with a vane angle of 45^{o} under stroboscopic light showed that liquid released by the fluid injector travelled along the inner vane surfaces to the outer rim when the drum was rotated in the same direction as the vanes, but when rotated in the opposite direction, liquid travelled along both inner and outer vane surfaces. This gave rise to a difference in atomisation between different rotation directions, producing differences in droplet size spectra.

Differences in droplet size spectra between drum rotation directions were also probably due to differences in the airstream velocity generated by the axial drum. Airstream velocity was higher with drum rotation in the same direction as the vanes, giving rise to lower VMD/NMD ratios and narrower droplet size spectra.

The decrease in the VMD/NMD ratio with the addition of teeth to the inner vane rim surface of a drum rotating in the same direction as the vanes was probably due to the teeth acting as zero issuing surfaces for ligament formation. The reduced surface width provided by each tooth caused a decrease in ligament width over that expected on a toothless surface. When the centrifugal energy overcame the surface tension binding ligaments to the teeth, relatively small droplets were produced. The addition of teeth to the outer vane peripheral surface did not affect droplet size spectra because liquid flowed across the inner vane surfaces only.

The addition of grooves to toothed drums probably assisted liquid channelling towards the teeth, allowing the actual speed of drop ejection to be equal to the drum peripheral speed (Fraser and Eisenklam, 1956). This probably caused the 20 μm reduction in droplet VMD obtained with the addition of grooves to vanes.

Chapter 4

FIELD TRIALS

4.1. INTRODUCTION

The results of the field trial experiments with grass and maize and grapefruit tree canopies are described seperately. Droplet size spectra and subsequently droplet deposition on target surfaces are described.

4.2. STUDIES IN GRASS AND MAIZE CANOPIES

DROPLET SIZE SPECTRA

Cypermethrin droplets sprayed by the AU8000 atomiser rotating at 13000 rpm in a 116 m/sec airstream were collected on rotary magnesium oxide coated slides and classified into size classes (Fig 4.1). Mean percentage frequencies of droplets in each size class according to number and volume distributions were calculated as cumulative percentages of droplets of different diameters (Fig 4.2). The data was corrected to allow for wind speed using the following equation for 6 mm wide slides rotating at 420 rpm around a radius of 65 mm:

Correction factor = 0.444 x wind speed (m/sec) (Cooper et al, 1987).

Fig 4.1. Droplet percentage distributions among size classes according to vol and no distributions for AU8000 in field.

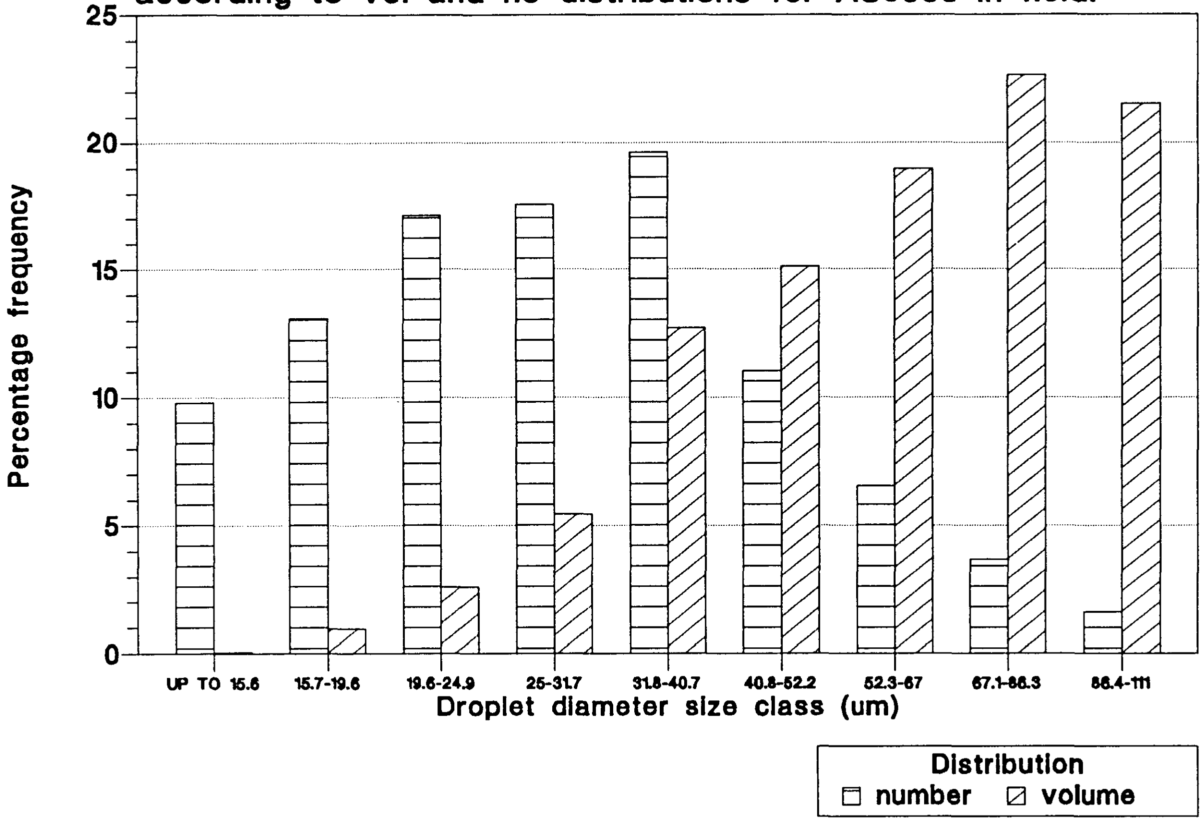
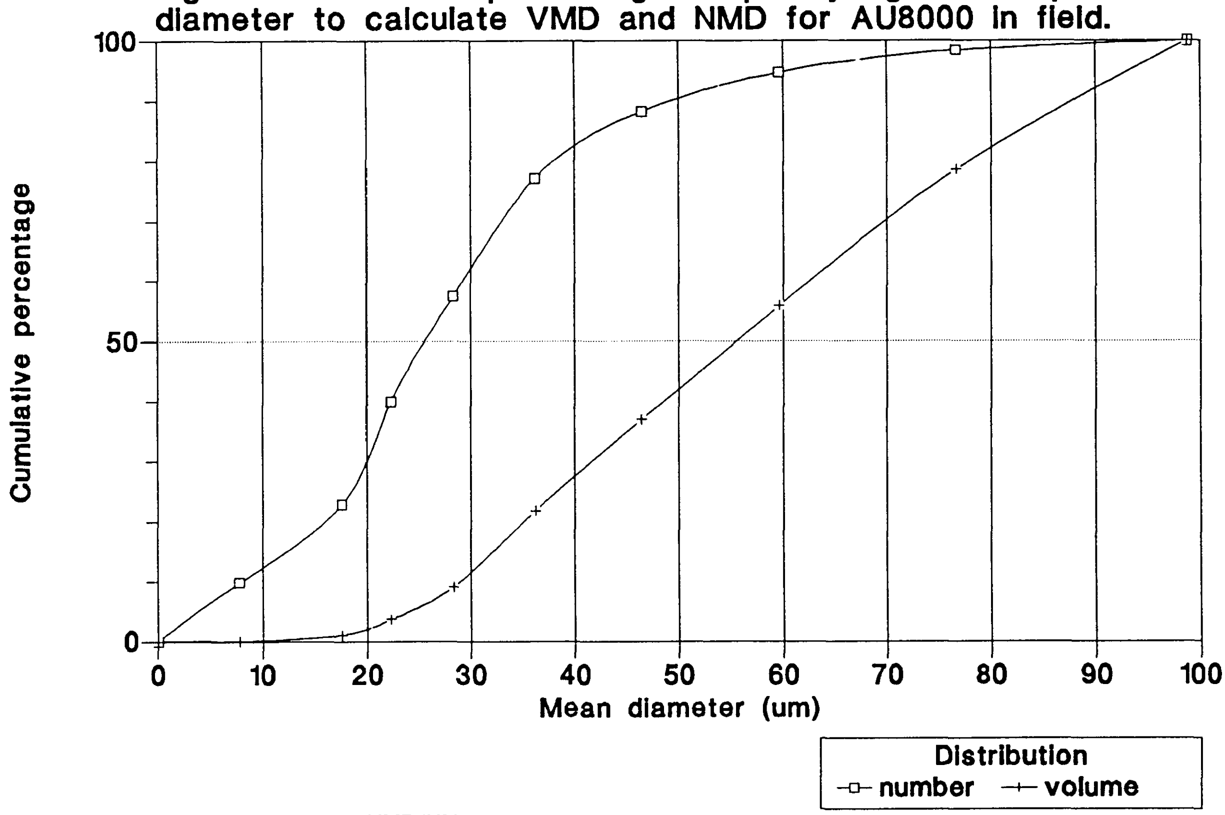


Fig 4.2. Cumulative percentage frequency against droplet diameter to calculate VMD and NMD for AU8000 in field.



VMD=55 NMD=25; VMD/NMD=2.2

The VMD of the spray was 55 μm and NMD was 25 μm, thus there was a VMD/NMD ratio of 2.2.

DROPLET DEPOSITION ON KROMEKOTE TARGETS AND CONTROL OF <u>SPODOPTERA EXEMPTA</u> LARVAE

Deposition of droplets from the manually carried motorised knapsack mistblower (Figs 4.3 to 4.6) and the vehicle mounted mistblower (Figs 4.7 and 4.8) all showed a peak deposition on targets within 10 m downwind and a rapid decline in droplet densities further downwind. There was no significant decrease in droplet density beyond 50 m downwind using the knapsack mistblower ($p<0.05$, SE=6.6, df=123) and 70 m for the vehicle-mounted machine ($p<0.05$, SE=5.4, df=41).

Significantly more droplets were collected on vertical targets placed at 0.3 m height than on horizontal targets at 0.3 m and on ground targets ($p<0.05$, SE=3.1, df=123 for the knapsack mistblower; $p<0.05$, SE=2.5, df=41 for the vehicle-mounted machine).

Six and twelve hours after application of cypermethrin, approximately 50 percent of the live larvae were moribund. Larval counts 24 hours after spraying only included larvae which had definately been killed (Tables 4.1 to 4.6). The 24 hour data was used for the data analysis.

Fig.4.3. Droplet deposition densities on different targets and larval mortality levels for hand-held Solo/AU8000, trial 1, 7/4/90.

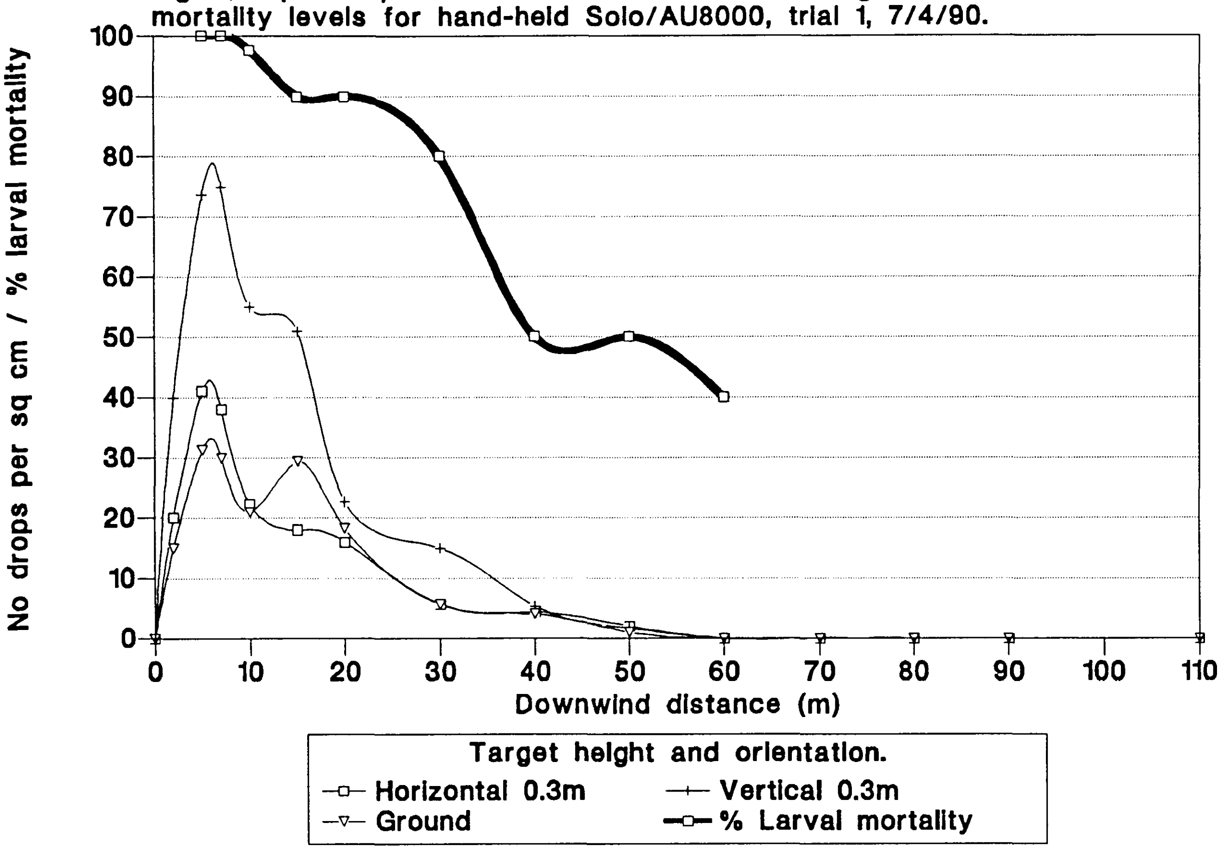


Fig. 4.4. Droplet densities on different targets and larval mortality levels for hand-held Solo/AU8000, trial 2, 10/4/90.

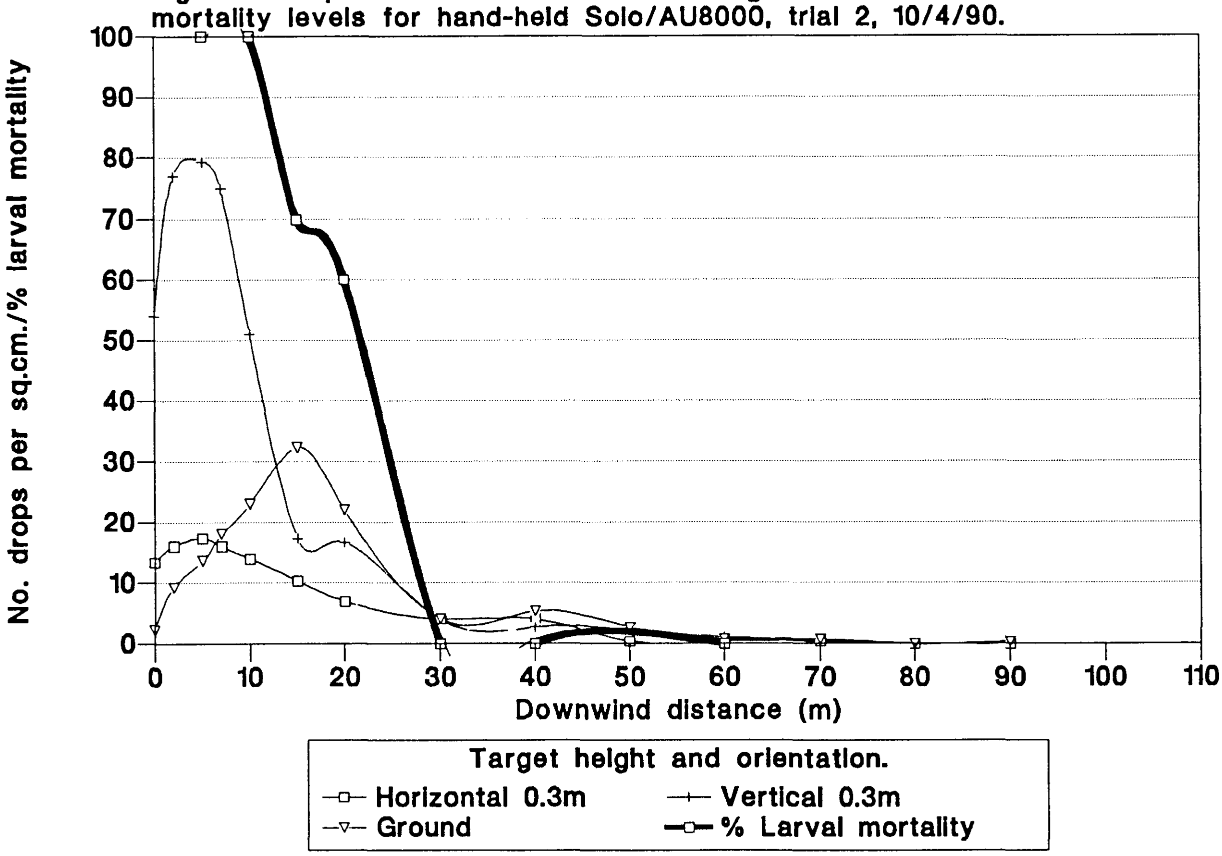


Fig. 4.5. Droplet densities on different targets and larval mortality levels for hand-held Solo/AU8000, trial 3, 19/4/90.

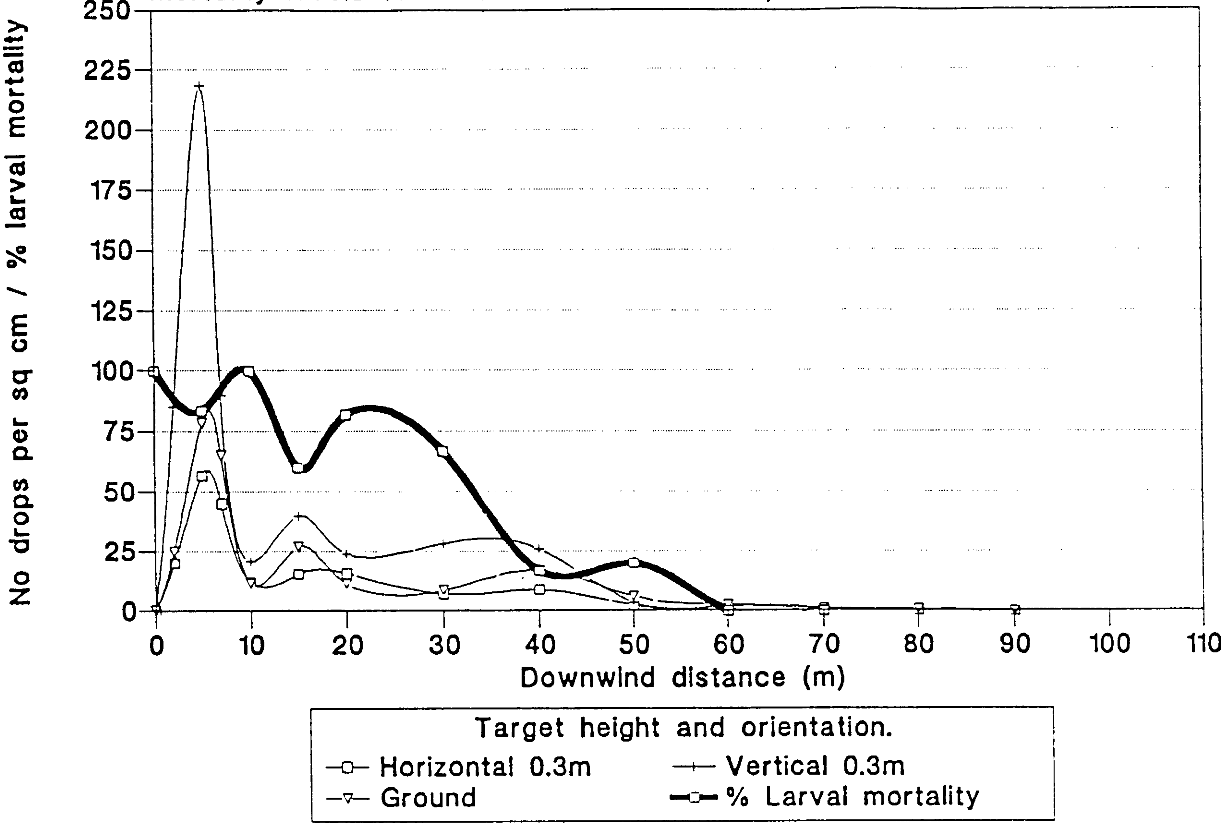


Fig. 4.6. Droplet densities on different targets and larval mortality leve's for hand-held Solo/AU8000, trial 4, 9/4/90.

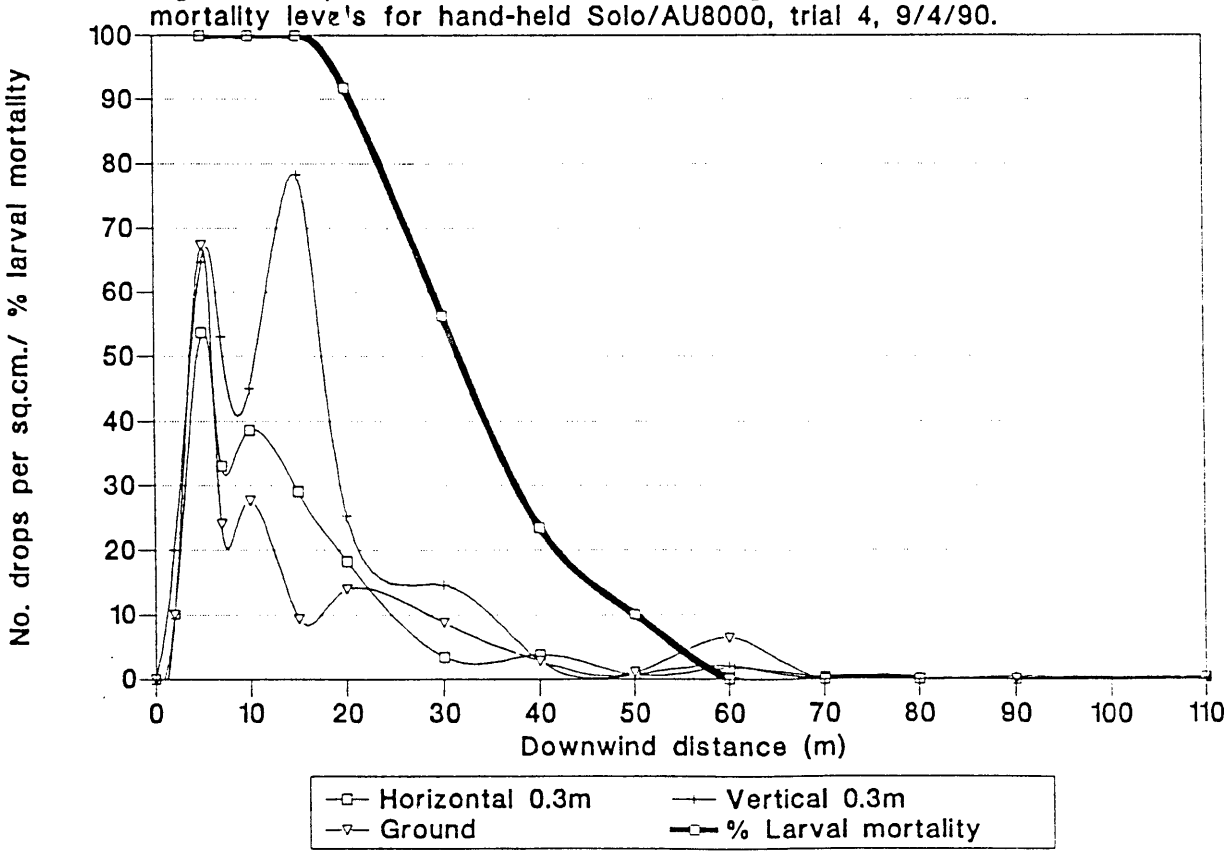


Fig. 4.7. Droplet densities on different targets and larval mortality levels for vehicle-mounted Solo/AU8000, trial 5, 18/4/90.

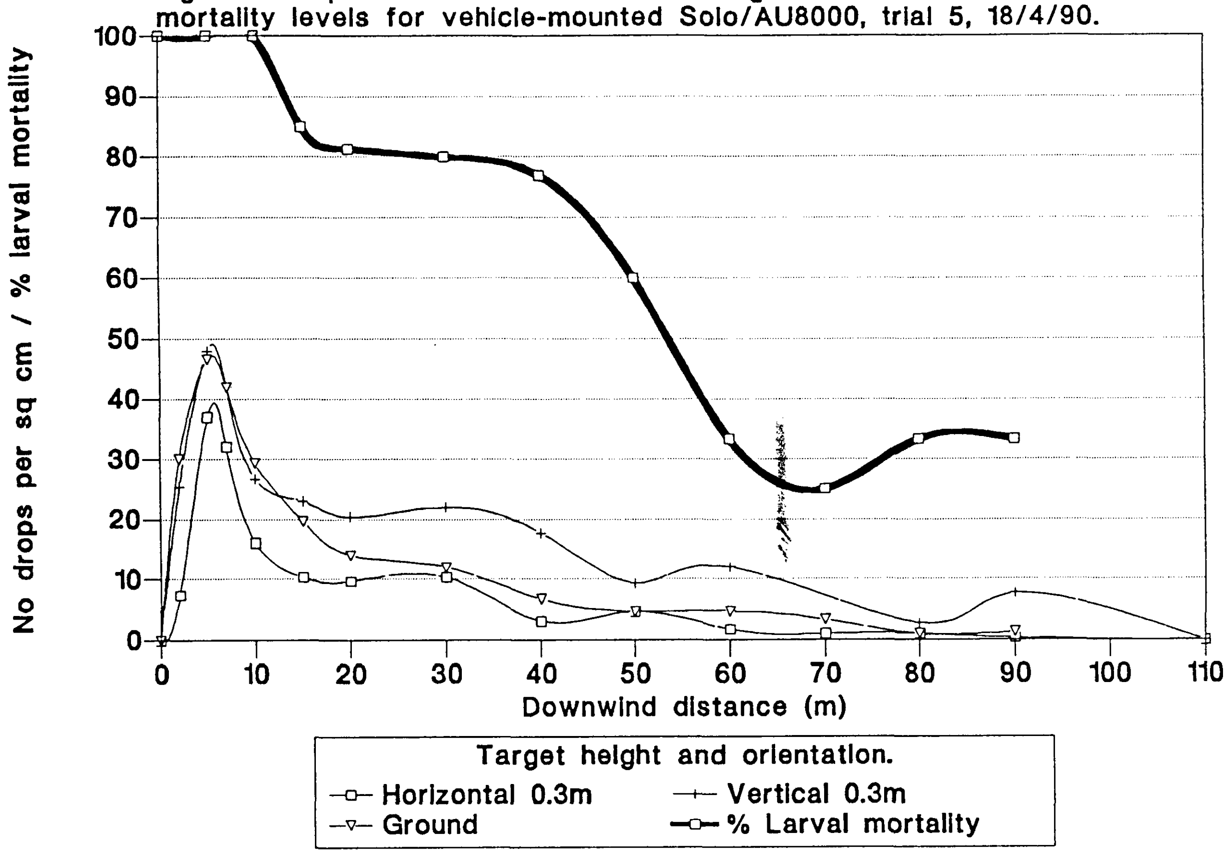


Fig. 4.8. Droplet densities on different targets and larval mortality levels for vehicle-mounted Solo/AU8000, trial 6, 18/4/90.

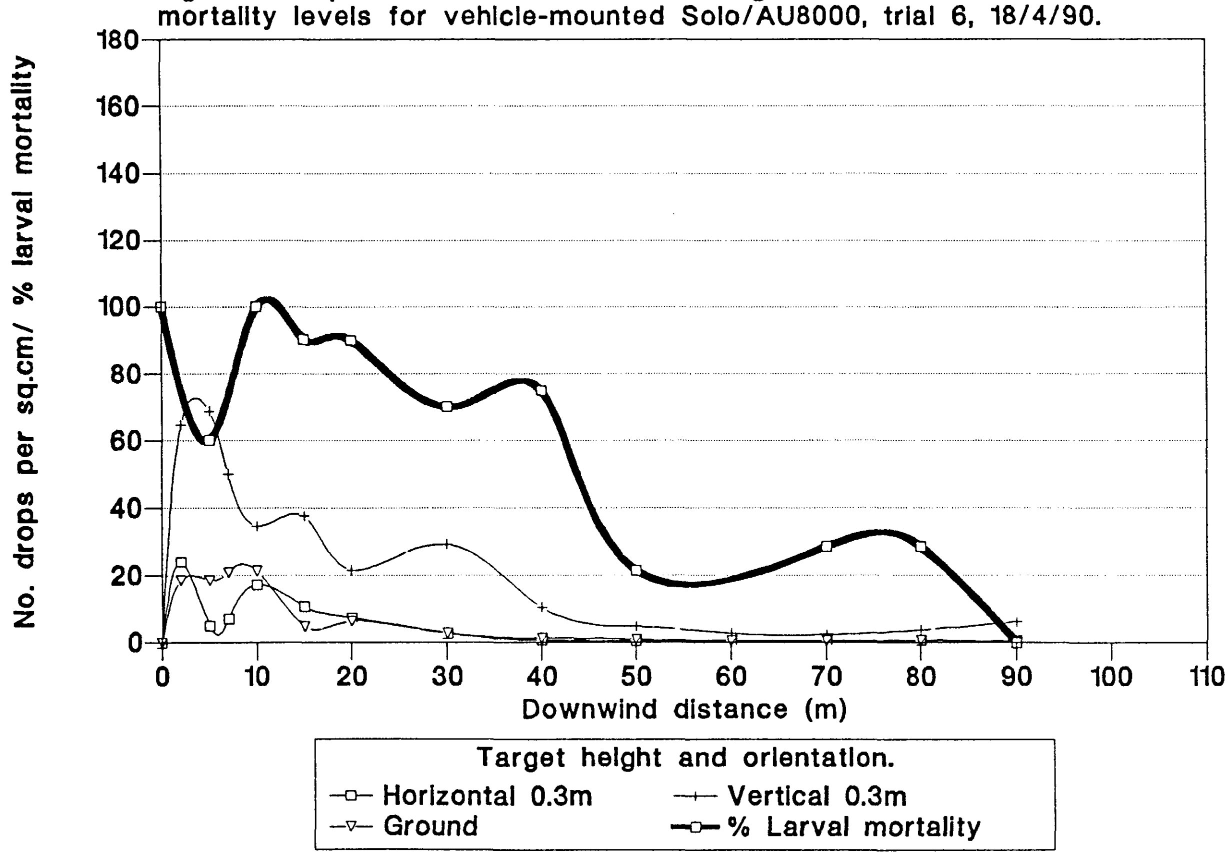
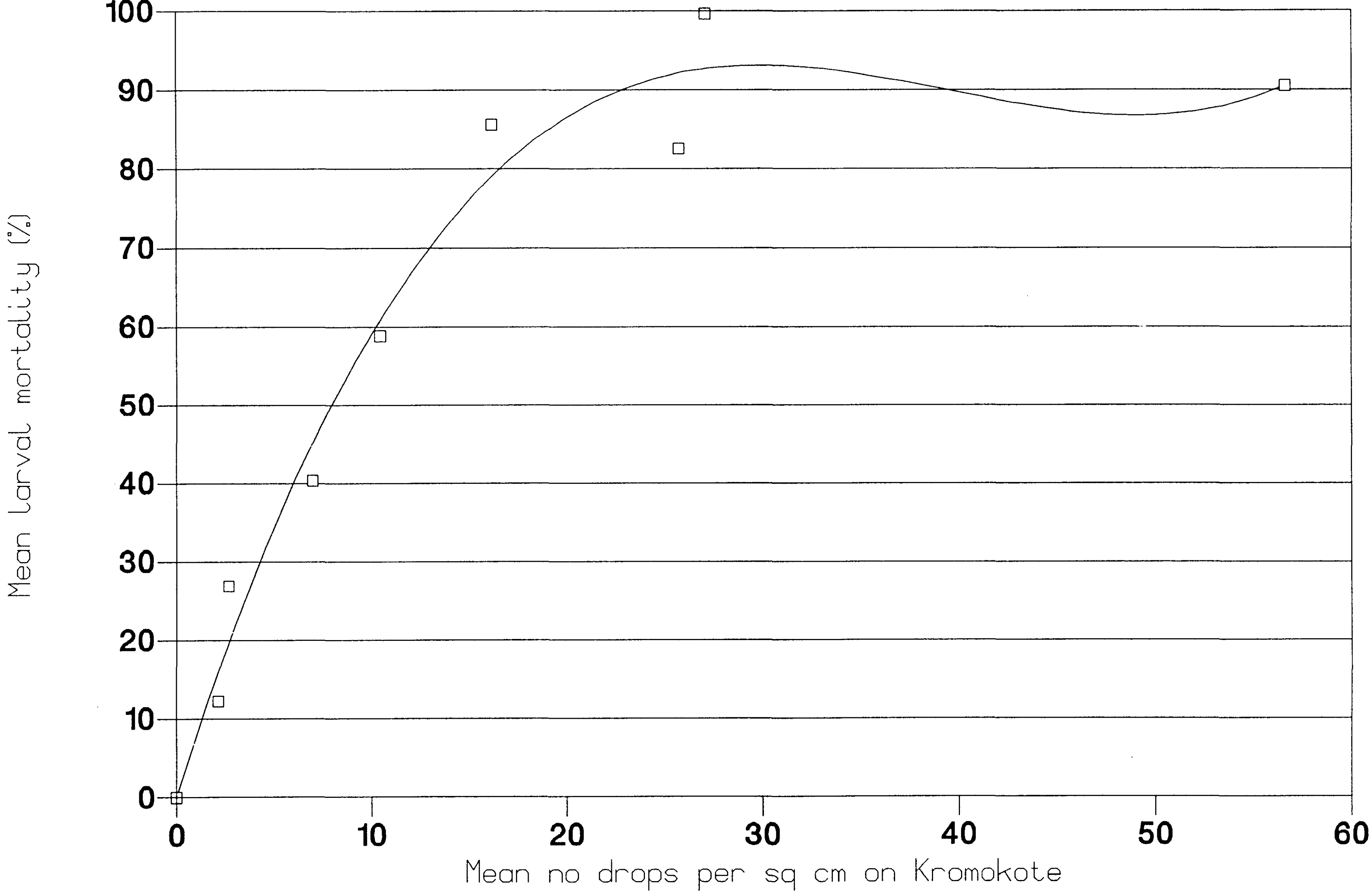


Fig 4.9 Mean larval mortality against mean droplet density on Kromokote targets for spray with 55um VMD, 25um NMD.



Larval mortality exceeded 70 percent within 35m downwind, but it was unlikely that all dead larvae were recorded as many were shrivelled or eaten by ants or birds. The mean mortality of larvae in grass and maize was plotted against mean droplet density on Kromekote papers (Fig 4.9). Since the grass and maize fields contained leaves with many orientations, the values are means of droplet densities on horizontal and vertical targets. There was a significant correlation between mean droplet density on Kromekote targets and mean larval mortality ($p<0.01$, $r^2=0.78$). Linear regression analysis was carried out on logarithmically-transformed mean droplet density and mean larval mortality data to develop the following empirical relationship between these parameters:

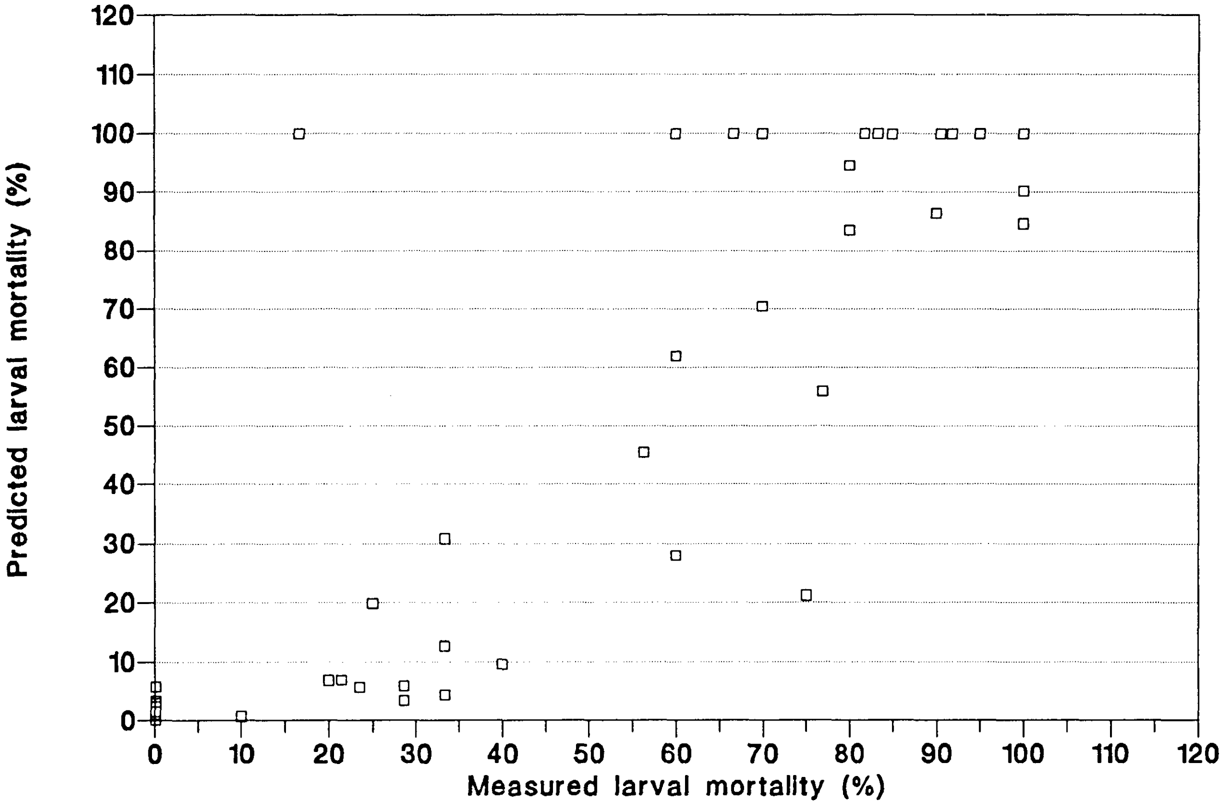
$$\text{Mean larval mortality (\%)} \approx 5.035.(\text{Mean no. drops/cm}^2)^{0.9}$$

This equation calculated an expected percentage larval mortality for a given mean droplet density on Kromekote paper targets. The following equation was also developed relating the number of droplets deposited per cm^2 on vertical (V) and horizontal (H) targets at 0.3m height to larval mortality:

$$\text{Mortality (\%)} \approx 1.3.(V)^{1.05}.(H)^{0.21} \quad (r^2=0.66,\ df=58)$$

Since mortality greater than 100 % is not possible, values exceeding 100 % were assumed to be 100 %. Under this assumption, the goodness of fit of the data to the model is shown on Fig. 4.10. The effect of droplet densities on

Fig 4.10 Scatter plot of predicted and measured larval mortality.



targets on the ground could not be accurately incorporated into this model.

DISCUSSION

The VMD and NMD values obtained when spraying cypermethrin through the AU8000 and water-based spray through the X1 atomisers in the field were slightly lower than predicted from the empirical models developed using laboratory droplet size data. VMD/NMD ratios were similar to those expected using the empirical models. The differences in VMD and NMD were probably due to differences in liquid physical properties, to higher rates of evaporation in the field and to the different sampling procedure adopted. In the laboratory, droplets were sized immediately after atomisation by a relatively non-intrusive laser beam 50mm from the atomiser. In the field, droplets were collected after longer periods of time and at distances up to 110m from the atomiser.

Whilst the collection efficiency of Kromekote paper targets is not exactly the same as collection efficiency on leaves, the artificial surfaces allowed more samples to be taken.

Variations in deposits were due to differences in the crop canopy and terrain affecting air movement when the droplets were beyond the influence of the artificial airstream. If more replicate trials could be carried out, these effects would probably reduce. However there were limitations of time and available trial sites.

The number of dead larvae recorded is very likely to give an underestimate of actual mortality since dead larvae tend to shrivel, especially the early instars, making them very difficult to see, and may be carried away by ants or birds.

No account was taken of immigration and emigration of larvae. However, larval densities in nearby untreated fields were very similar before and after each trial so the effects of immigration and emigration were probably negligible. The mobility of the larvae was important in affecting the accuracy of the empirical models developed to correlate droplet densities with larval mortality levels. Many larvae did not die until 6 to 24 hours after the application of cypermethrin. In this time period, they could move from the site of poisoning to another sample site. It is difficult to control such movements in the field environment.

These trials indicate that a minimum of approximately 9 droplets of a 2.4 % ULV formulation of cypermethrin would be required per square centimetre to achieve 50 percent larval kill (LN_{50}). 95 percent mortality (LN_{95}) would require approximately 28 droplets/cm^2. These minimum droplet densities would vary according to larval maturity, pesticide, uniformity of spray deposition, wind speed and droplet size.

Individual pesticide droplets exert an influence beyond their boundaries (Ford and Salt, 1987). The term biocidal area has been used to describe the area around a droplet in which at least 50 % of the larvae are killed (Munthali, 1981). It is equal to half the treated area divided by the LN_{50} value. The biocidal area in this study was therefore approximately $4.5mm^2$.

This study investigated droplet distribution densities and larval mortality across a single swath only. The results can be used to decide the track spacing required to achieve required larval mortalities over a larger area. Suitable track spacings were estimated to be 25 and 45 m respectively for back-mounted and vehicle-mounted mistblowers to achieve 50 % larval mortality. As an example, the cumulative droplet densities required to achieve 95 % and 80 % larval mortalities using overlapping swaths are illustrated in Figures 4.11 and 4.12 respectively.

4.3. STUDIES IN GRAPEFRUIT TREE CANOPIES

DROPLET SIZE SPECTRA

Mean percentage frequencies of droplets in size classes according to number and volume distributions were calculated as cumulative percentages of droplets of different mean diameters in order to calculate VMD and NMD values (Appendix 2). The VMD and VMD/NMD ratio increased

Fig 4.11 Droplet densities expected using 18 m track separations to achieve 95 % larval mortality.

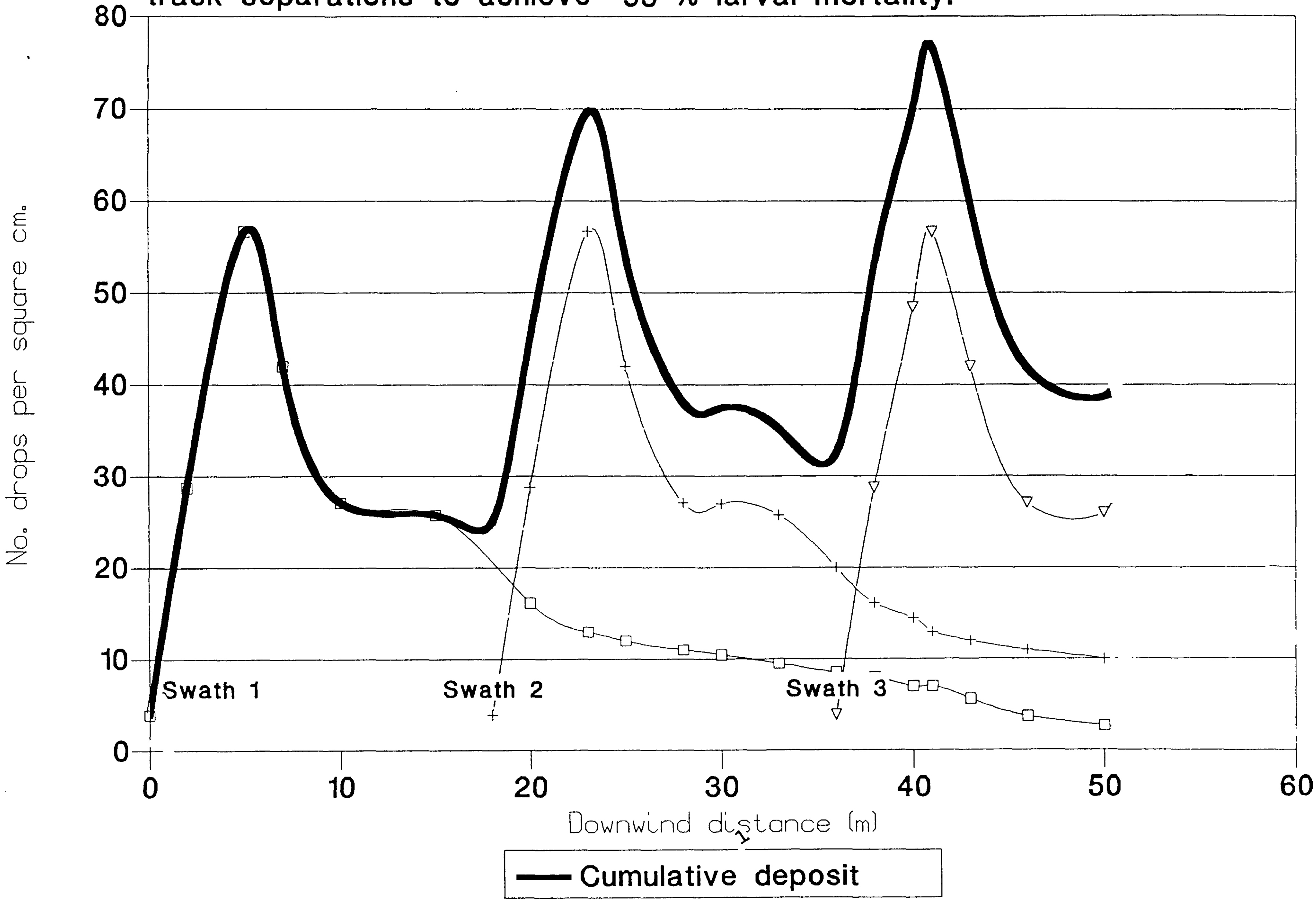
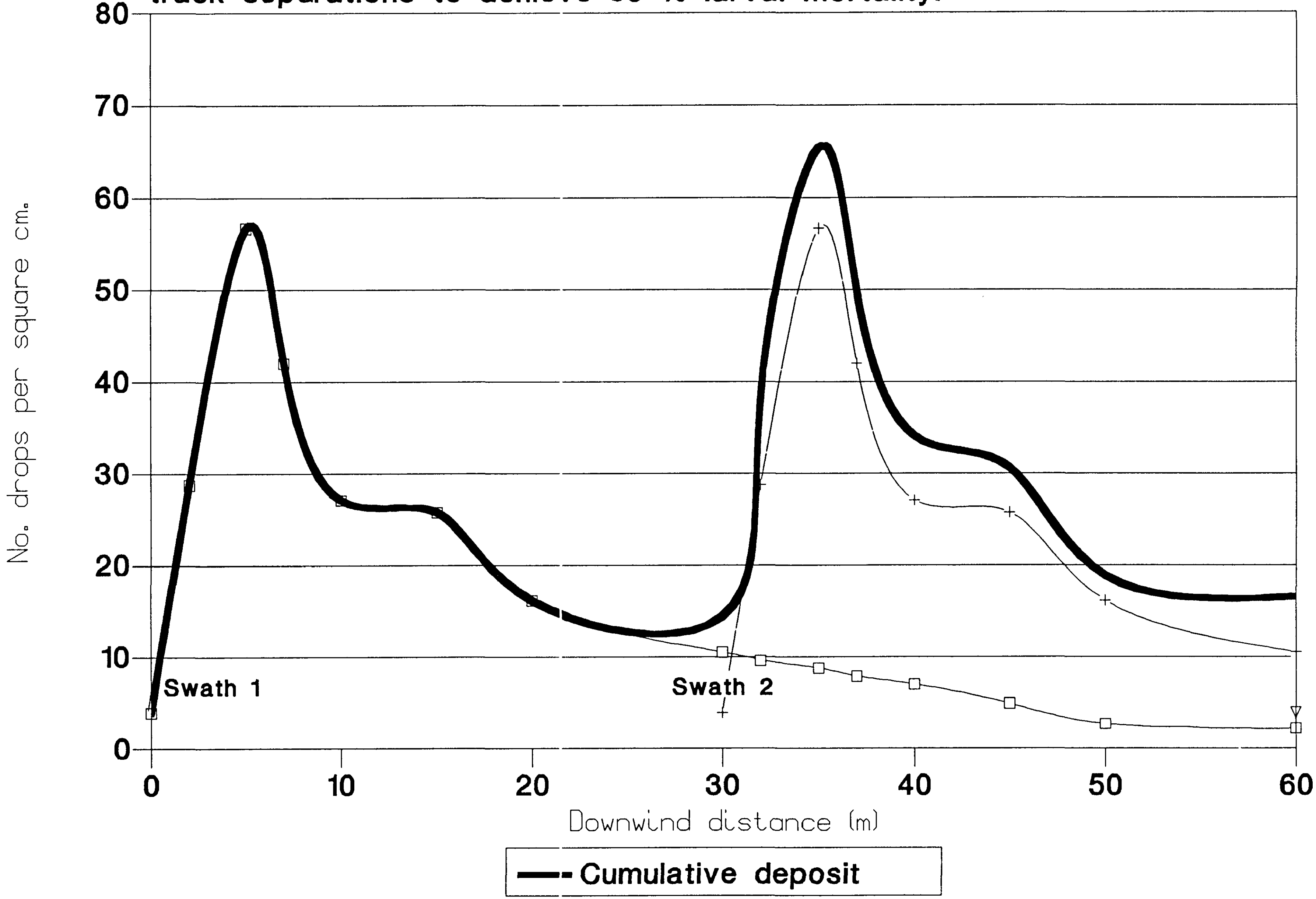


Fig 4.12 Droplet densities expected using 30 m track separations to achieve 80 % larval mortality.



with increasing flow rate, decreasing rotation rate and decreasing airstream velocity (Figs 4.13 and 4.14).

The X1 volumetric and numeric droplet size distribution spectra were mono-modal (single peak) at all flow rates except 500 and 700 ml/min, where bimodal spectra occurred. The VMD increased from 43 to 180 μm and the VMD/NMD ratio increased from 1.3 to 6.2 as the flow rate increased from 300 to 2000 ml/min.

The hollow cone ceramic nozzle droplet size spectra were bi- and tri-modal. The VMD varied from 458 to 498 μm and the VMD/NMD ratio varied between 9.3 and 14.1 The rate of change in VMD with flow rate was less for the hollow cone nozzle than the X1 atomiser.

DROPLET DEPOSITION WITHIN TREE CANOPIES

Leaves removed from different locations within each tree were analysed for percentage coverage with droplets under ultra-violet light illumination in a dark room. The dye fluoresced strongly allowing easy visual assessments of droplet coverage. The water-sensitive papers showed very similar coverage to the assessments made using the fluorescent tracer but were more difficult to analyse due to liquid spread and leaf-to-leaf contact (Appendix 2).

Fig. 4.13 VMD against liquid flow rate for X1 and hollow cone atomisers in different airstream velocities.

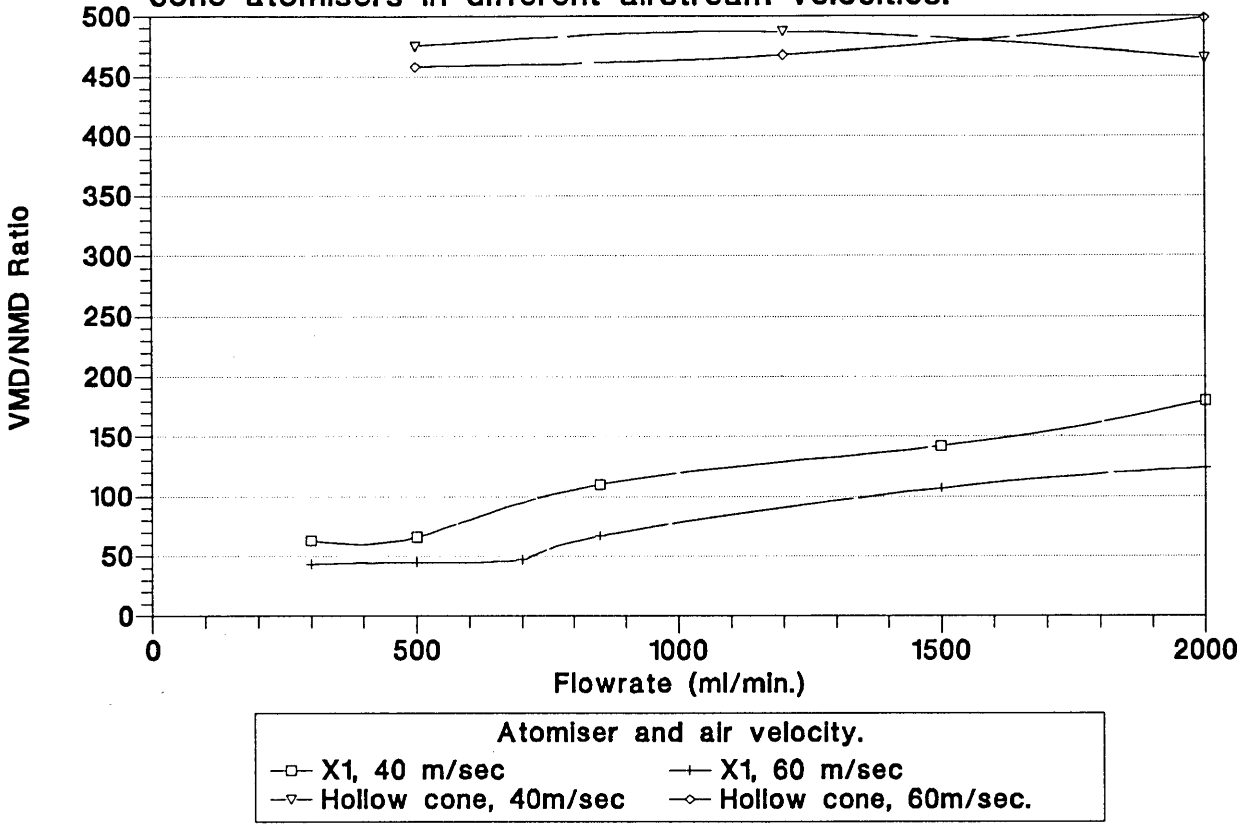
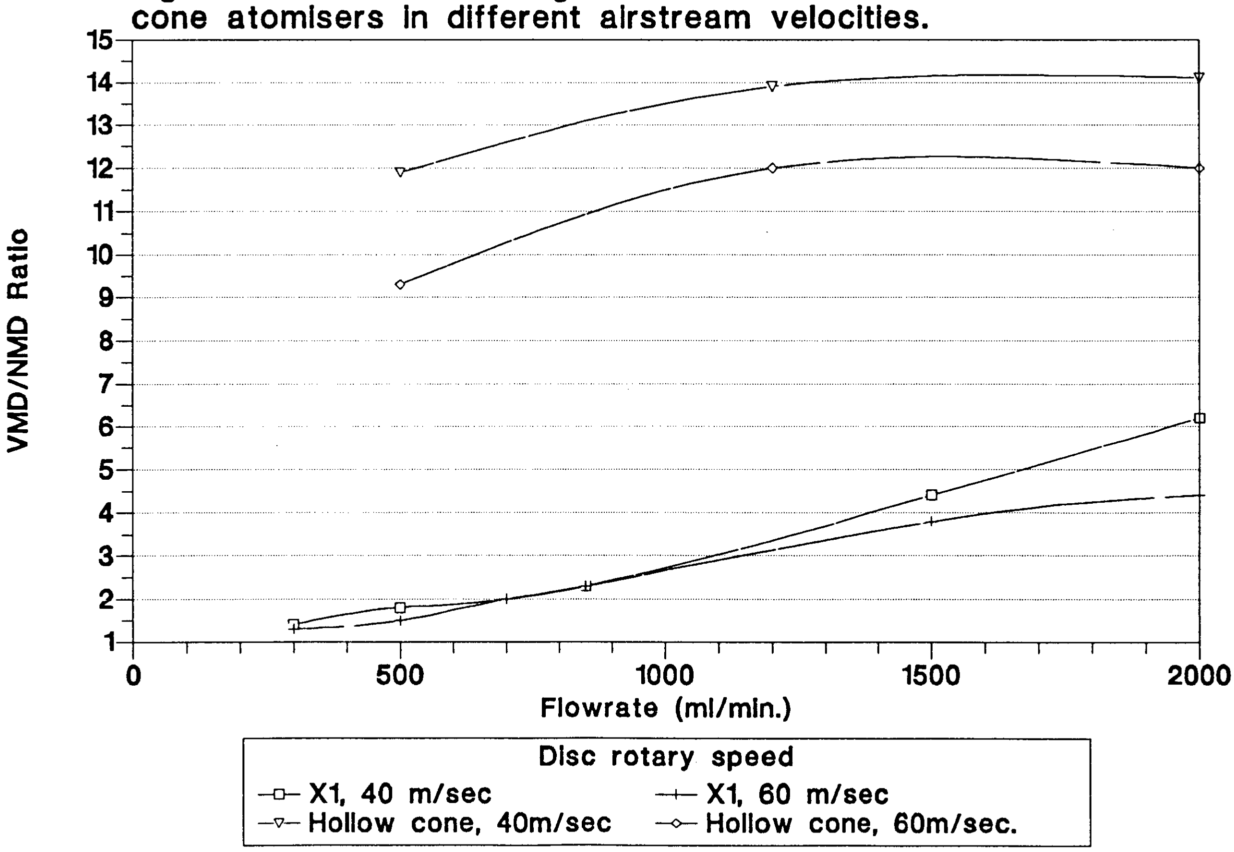


Fig. 4.14 VMD/NMD ratio against flow rate for X1 and hollow cone atomisers in different airstream velocities.



Mean percentage cover on sample surfaces increased with increasing spray volume application rate (Fig. 4.15).

Mean coverage of all leaves and trunk was 97 to 100 percent at an application volume of 25 l/tree with the X1 atomisers. Coverage using the hollow cone nozzles at the same rate was poorer, especially on inner leaf and trunk surfaces, with mean coverage of only 53 and 57 percent on some surfaces.

At 12.5 l/tree application rate, mean coverage on all leaf surfaces was 93 to 100 percent using the X1 atomisers. Mean coverage using the hollow cone nozzles was lower, ranging from 55 to 87 percent. Coverage on the trunk using the X1 atomisers ranged from 90 to 97 percent, and from 30 to 43 percent using the hollow cone nozzles.

Even when the volume applied with the X1 atomisers was reduced to 6 l/tree, mean coverage was greater than when the hollow cone nozzles applied 12.5 l/tree, with leaf coverage ranging from 57 to 83 percent and trunk coverage from 43 to 60 percent.

The mean relative coverage at each sampling position was calculated for all trees at each volume application rate (Figures 4.16 to 4.20). At application volume rates of 12.5 and 25 l/tree, similar coverage was observed at all sampling positions in trees sprayed using X1 atomisers. Coverage in trees sprayed using the hollow cone ceramic nozzles was approximately 50 percent lower on inner leaf

Fig. 4.15 Mean percentage droplet coverage on tree sampling sites at different volume application rates using X1 and hollow cone atomisers.

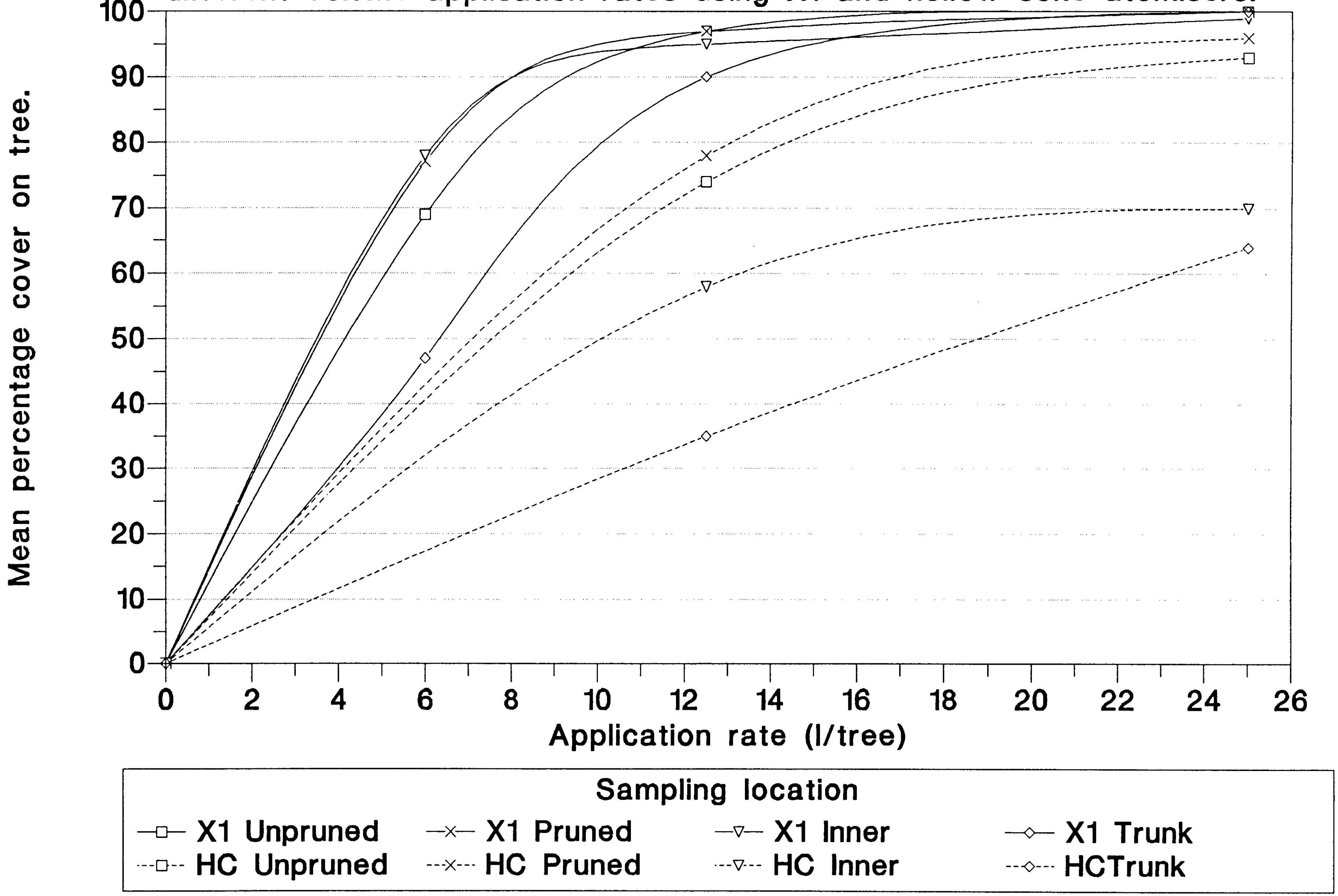


Fig. 4.16. Relative distribution of spray within a grapefruit tree canopy sprayed at a volume rate of 12.5 l/tree using hollow cone nozzles.

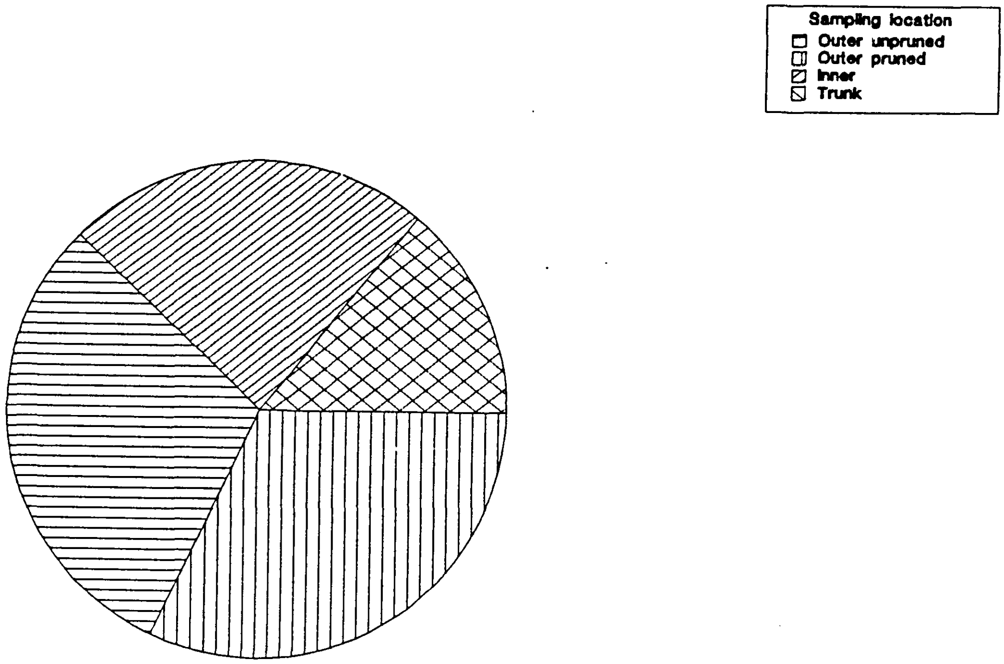


Fig. 4.17. Relative distribution of spray within a grapefruit tree canopy sprayed at a volume rate of 25 l/tree using hollow cone nozzles.

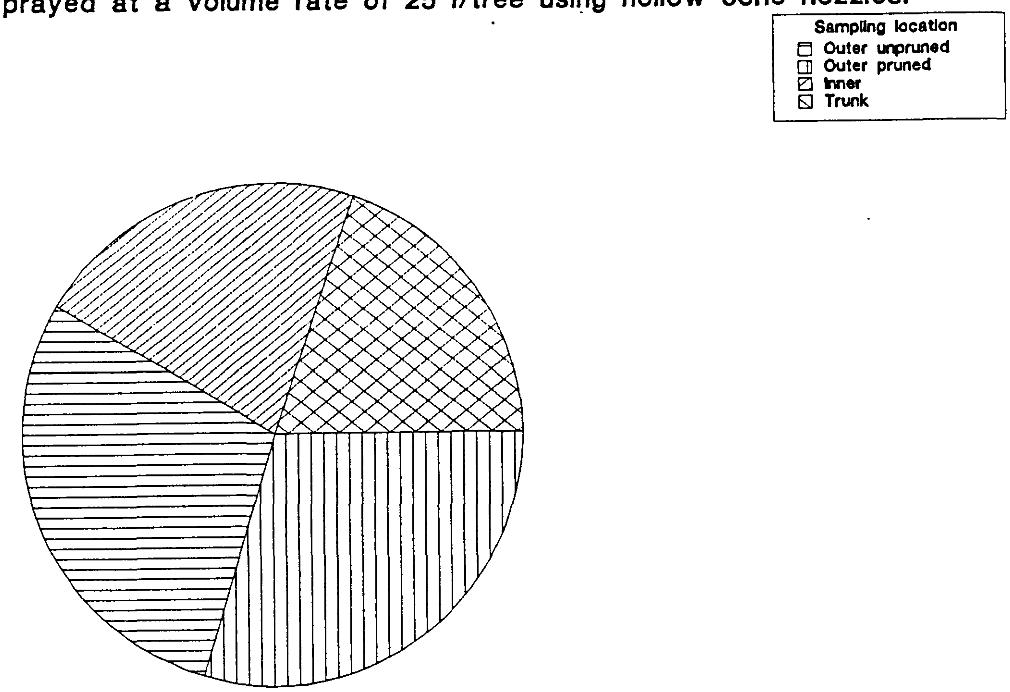


Fig. 4.18. Relative distribution of spray within a grapefruit tree canopy sprayed at a volume rate of 6 l/tree using X1 atomisers.

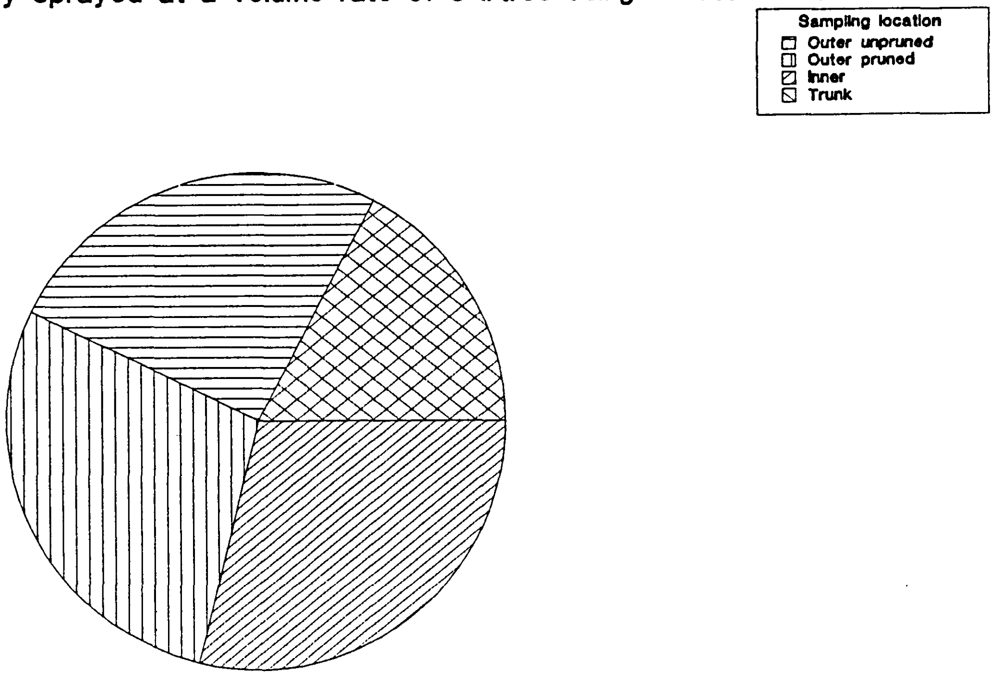


Fig. 4.19. Relative distribution of spray within a grapefruit tree canopy sprayed at a volume rate of 12.5 l/tree using X1 atomisers.

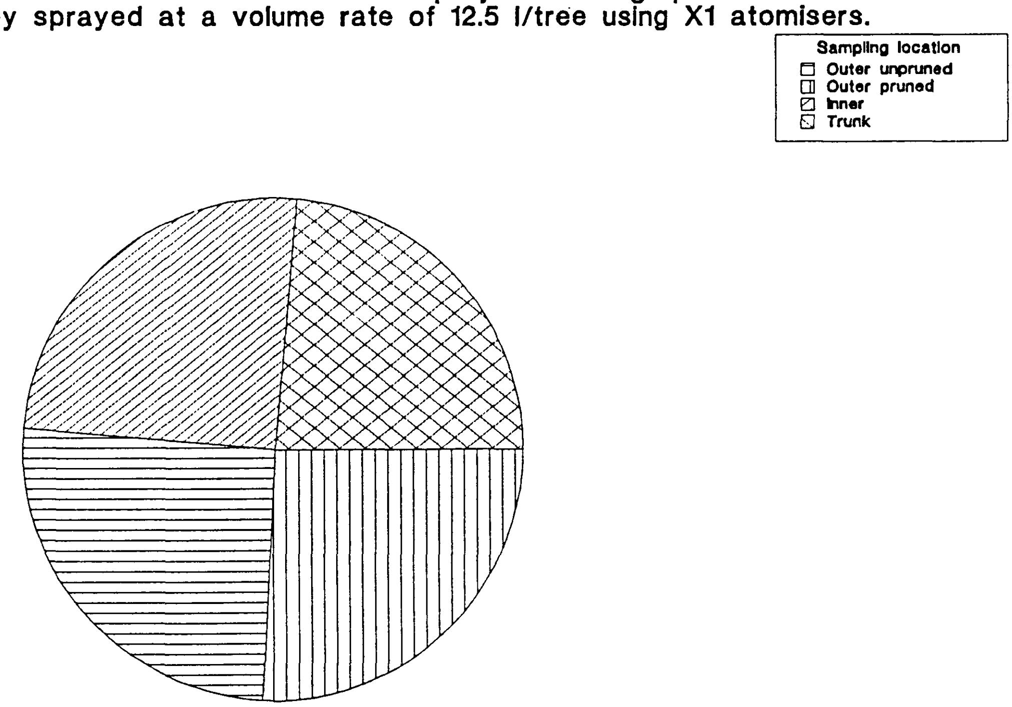
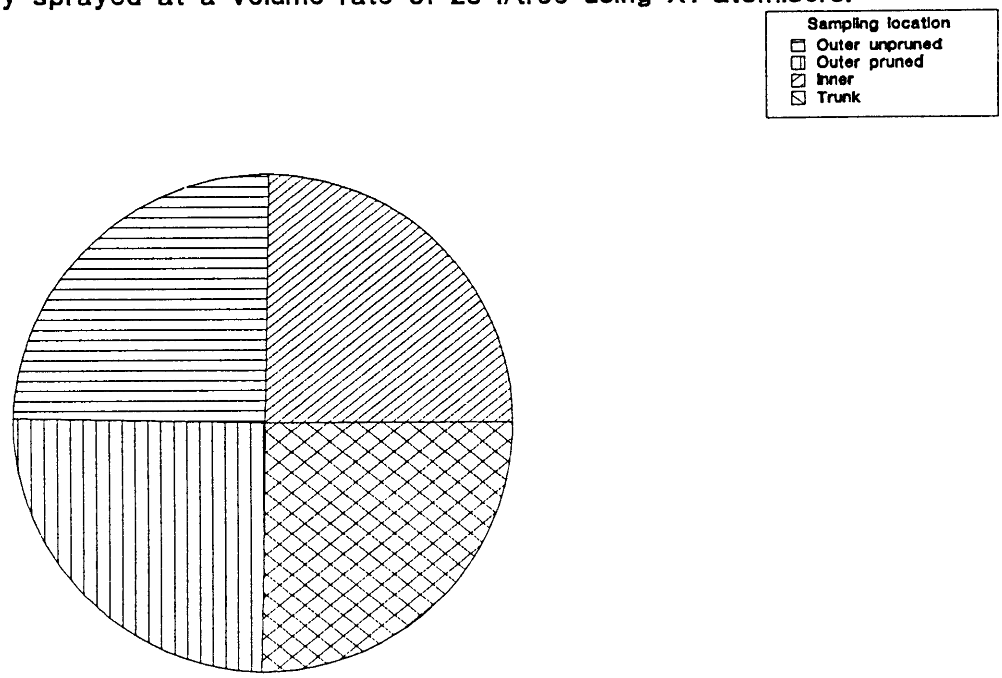


Fig. 4.20. Relative distribution of spray within a grapefruit tree canopy sprayed at a volume rate of 25 l/tree using X1 atomisers.



and trunk sampling positions than on outer leaf positions. Therefore a more even distribution of spray was obtained using the X1 atomisers at equal and reduced application volume rates to the hollow cone nozzles.

SPRAY LOSS TO GROUND BENEATH TREES

Volumes of spray collected on polythene sheeting placed beneath trees whilst spraying were between 69 and 73 percent lower when X1 atomisers were used compared to the hollow cone nozzles (Table 4.7).

TABLE 4.7. LIQUID VOLUME COLLECTED BENEATH TREES.

Atomiser or nozzle	Mean volume applied (l/tree)	Mean volume collected (l/tree)	Percentage loss to ground
X1	25.0	1.7	6.8
X1	12.5	0.7	5.6
X1	6.0	0.2	3.3
Hollow cone	25.0	5.5	22.0
Hollow cone	12.5	2.6	20.8

DISCUSSION

The magnesium oxide method is not very suitable for measuring droplet diameters larger than approximately 200 μm (Matthews, 1979), so the hollow cone ceramic nozzle droplet size data is of limited accuracy. This study did not aim to accurately assess the droplet size spectra of the FMC 1087 hollow cone ceramic nozzles, but to obtain approximate droplet size data to explain differences in spray coverage achieved with that obtained using the X1 atomisers.

The relatively poor coverage with few droplets on inner leaf and trunk surfaces observed using the hollow cone nozzles indicates that spray penetration was relatively low compared to that achieved using the X1 atomisers. This was mainly due to the difference in the droplet size spectra of the two atomisers. VMD values of 465 to 498 μm for the hollow cone nozzles were considerably larger than the 67 to 85 μm VMD sprays produced by the X1 atomisers in these trials. A reduction in droplet size should result in similar coverage of tree surfaces at reduced liquid volume rates since there is a cubic relationship between droplet diameter and volume. A droplet twice the diameter of another will contain twice cubed, or eight times the volume of liquid. The 67 to 85 μm VMD spray produced by the X1 atomisers would therefore be expected to give higher coverage per unit area than the 465-498 μm VMD spray from the hollow cone nozzles.

Another factor is the large droplets produced by the hollow cone ceramic nozzles with their low terminal velocities remain in the airstream only over relatively short distances.

These comparative coverage observations are similar to those of Furness and Pinczewski (1985) and Raisigl and Felber (1991) who obtained considerable improvements in coverage on trees by replacing hydraulic nozzles with slotted rotary drum and X1 atomisers respectively producing spray with a smaller VMD and VMD/NMD ratio.

A problem associated with spraying small droplets such as those produced by the X1 is evaporation, especially at high air temperatures, high wind speeds and low relative humidities. Loss of liquid by evaporation may have been higher for the X1 than the hollow cone nozzles, although this was not assessed. Ambient air temperature during the trials was 25 to 31$^{\circ C}$ and relative humidity was 76 to 88 %. Drift is unlikely to have been a large problem as wind speed was always less than 1 m/sec. The addition of anti-evaporants to the spray liquid would be recommended to reduce losses by evaporation in low and ultra-low volume spraying using small droplets (Wogadeneh and Matthews, 1981).

Although quantitative droplet density assessments were similar using water-sensitive papers and fluorescent dye deposits on leaves, the papers required careful handling to avoid causing them to change colour with contact with moist fingers or other papers.

The 70 percent reduction in spray volume lost to the ground beneath trees sprayed using X1 atomisers was probably due mainly to increased spray deposition on tree and leaf surfaces.

Chapter 5

GENERAL DISCUSSION

5.1. INTRODUCTION

A discussion of the comparative laboratory and field performance of the atomisers is presented with particular reference to the relative suitability of each atomiser for the controlled droplet application of pesticide sprays with droplet diameters in the range 40-100 μm for the control of migrant pests such as Spodoptera exempta.

5.2. DROPLET SIZE PARAMETERS AND THEIR MEASUREMENT

As discussed in Chapter 2, many different parameters have been used to describe the droplet size spectra produced by atomisers. It is not possible to completely describe a droplet spectrum with a single parameter. In this study, the volumetric droplet size spectra have been described by the VMD, VAD and with selective graphs showing the volumetric distributions of droplets among size classes. To express the volume of spray contained by droplets with the diameter considered to be optimal for the control of Spodoptera exempta larvae, a parameter "VO" was used.

In order to express the uniformity of each spectrum, numeric droplet size distributions among size classes were derived using computer software to analyse the volumetric data which had been rounded to two decimal places (Bateman, 1989) given by the Malvern PSA. The number distribution data should be treated with caution because Malvern instruments do not actually count droplets but instead utilise a pattern of light scattering on diodes to derive volumetric size class distribution data. The NMD values calculated using magnesium oxide-coated slides are also of limited accuracy because it is difficult to assess the number of droplets with diameter below 15 μm due to their small size and low impaction efficiency. However, the 799 mm focal length lens used with the Malvern PSA in this study also does not account for droplets with diameter below 15 μm.

Johnstone (1978) and Matthews (1979) suggested that, in order to be termed "CDA", a spray should have a VMD/NMD ratio not exceeding 1.4 when measured using magnesium oxide coated slides, although this value might be higher when using VMD/NMD ratio data obtained using Malvern PSA (Bateman, 1989). The ratios obtained in this study indicate that CDA is attainable with the X1 atomisers when operated at flow rates not exceeding 1500 ml/min in an airstream with a velocity above 100 m/sec, and at flow rates not exceeding 500 m/min at lower airstream velocities. CDA according to the above definition was not obtained with the other atomisers involved in this study.

Because the VAD is also derived using numeric distribution, it also has limited accuracy. The relatively low accuracy of the numeric distribution data explains in part the difficulties encountered deriving accurate empirical models to predict the VMD/NMD and VAD of sprays.

The VMD and VMD/NMD ratio values obtained in this study are within similar ranges to those obtained in similar studies with motorised knapsack mistblower air-shear nozzles (Thornhill, 1983); X1 atomisers (T. Bals, personal communication) and slotted rotary drum atomisers (R. Kinnersley, personal communication; Rokicki and Wills, 1987). The author is not aware of similar studies involving the AU8000 rotary cage atomiser.

Whilst the droplet size measurements obtained using the Malvern laser and magnesium oxide-coated slide techniques were similar, they may differ from those expected using different droplet sizing techniques. The VMD values obtained by Bateman (1989) using a Particle Measuring System (PMS) instrument were 92 to 98% larger than those obtained for similar equipment operated under similar conditions with the Malvern ST1800 PSA whilst readings taken an Aerometrics particle size analyser were similar to those of the Malvern machine.

5.3. COMPARISON OF THE DROPLET SIZE SPECTRA PRODUCED BY DIFFERENT AIR-ASSISTED ATOMISERS UNDER SIMILAR OPERATIONAL CONDITIONS

The lowest VMD and VMD/NMD ratio respectively produced by each air-assisted atomiser when water+Agral was sprayed at liquid flow rates between 100 and 1500 ml/min were compared (Figs 5.1 and 5.2). Although the VMD produced by the X1 atomiser rose at a higher rate than the other atomisers with increasing flow rate, the X1 produced spray with a smaller VMD/NMD ratio at airstream velocities typically produced by motorised knapsack mistblowers with liquid flow rates up to at least 1500 ml/min.

The Noric slotted rotary drum atomisers were only able to produce VMD and VMD/NMD ratio values as low as the other atomisers operated in an airstream with velocity 116 m/sec when the drums were shrouded. This is because the shroud effectively only allowed a selective part of the total spray cloud to be released. Whilst this may be useful in a tunnel sprayer where liquid not released through the shroud window can be collected and re-circulated, shrouding would not be suitable for applications where liquid re-circulation is not possible. When operated without a shroud the lowest VMD range obtained using a Noric slotted rotary drum atomiser with air-assistance (40 m/sec) was 90 μm at a liquid flow rate of 100 ml/min increasing to 135 μm at a flow rate of 1500 ml/min. The VMD/NMD ratio varied from 2.4 at a flow rate of 100 ml/min to 6.0 at 1500 ml/min flow rate.

The percentage volume of spray contained by droplets with diameter 40-100 μm (VO) was of particular interest in this study. When fitted to a 3 HP motorised knapsack mistblower, the AU8000 atomiser rotating at 13000 rpm increased the spray VO by 32 to 52 % above that obtained with the Semco air-shear nozzle (Fig 5.3). A further increase of approximately 30 % was obtained using the X1 atomiser rotating at 15000 rpm with a liquid flow rate of 100 ml/min, however, the difference in VO between the AU8000 and X1 atomisers decreased rapidly to approximately 5 % at higher flow rates. When the airstream velocity was increased to 116 m/sec, 98 to 99 % of the spray volume atomised by the air-shear and rotary atomisers with a flow rate of 100 to 300 ml/min was contained in droplets with diameter 40 to 100 μm. This decreased at higher flow rates, with 82 to 95 % of the spray volume being contained by 40-100 μm diameter droplets at a flow rate of 1500 ml/min.

The shrouded Noric atomiser could selectively produce spray with a VO of 98-99 % at flow rates of 100 to 300 ml/min, however this fell to 70 % as liquid flow rate increased to 1500 ml/min. Where a shroud was not used, VO decreased from 65 % to 39 % as flow rate rose from 100 to 1500 ml/min.

Fig5.1VMD against flow rate of water+Agral sprayed through different atomisers and nozzles in different airstream velocities.

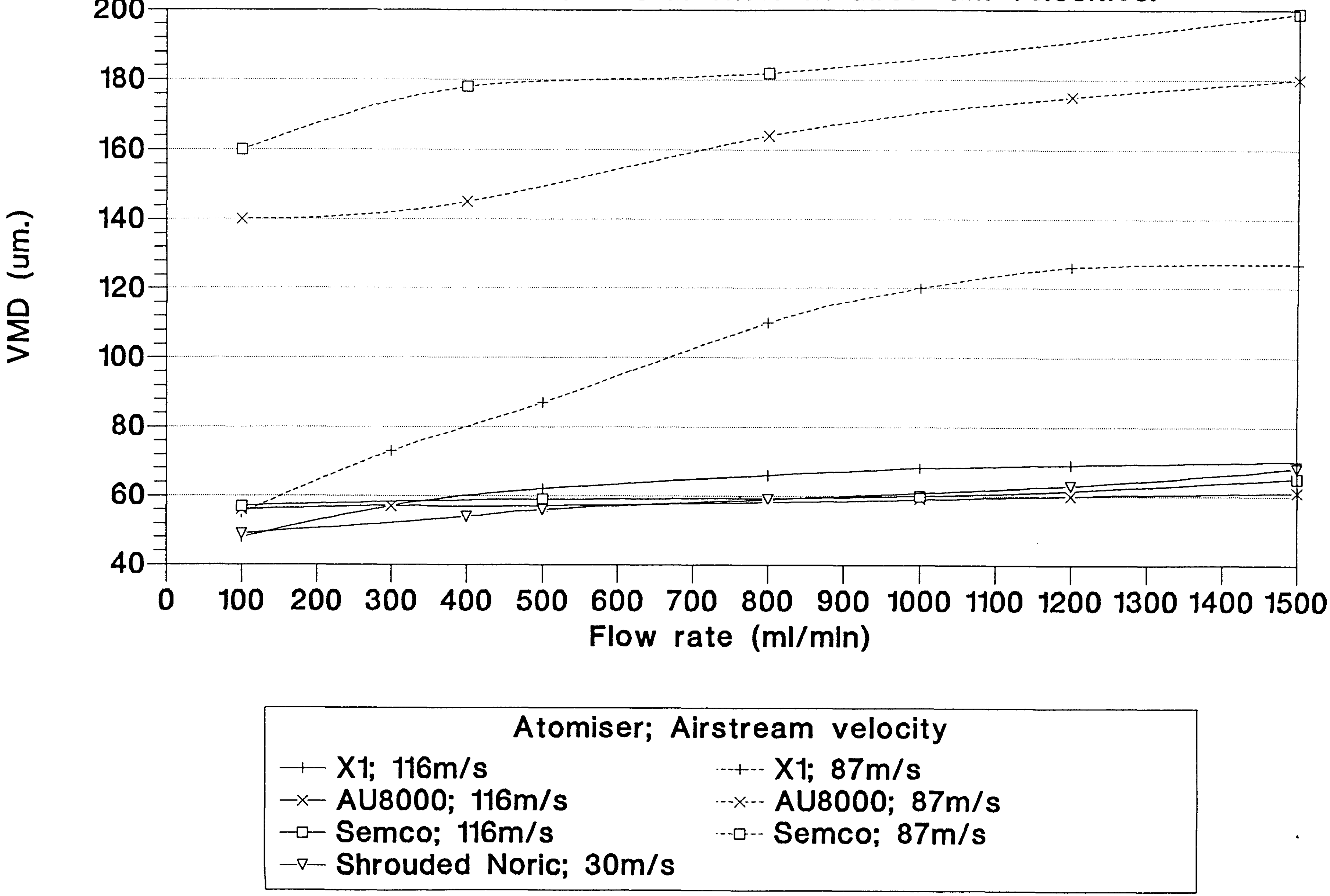


Fig5.2 VMD/NMD ratio against flow rate of water+Agral sprayed through different atomisers and nozzles in different airstream velocities.

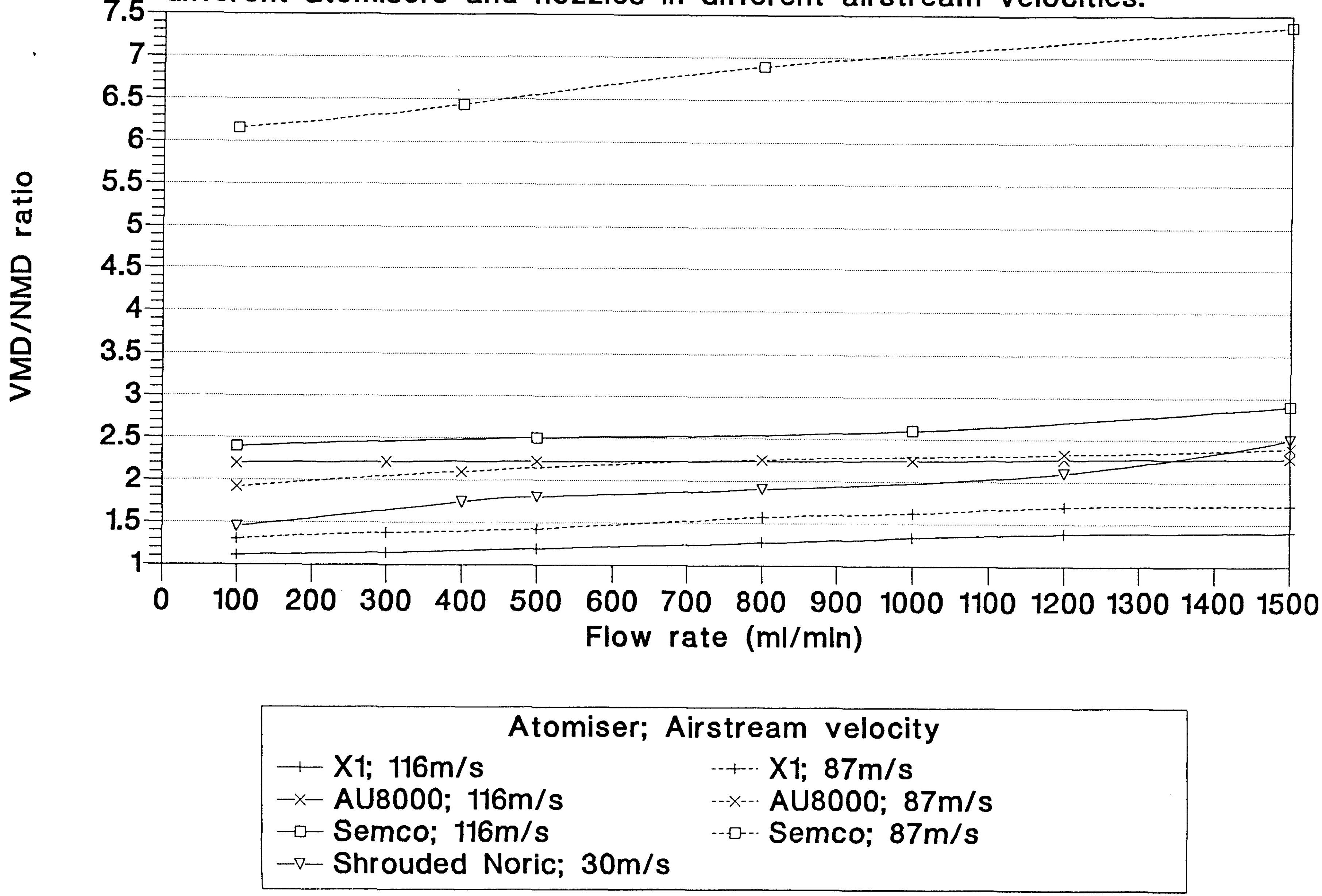
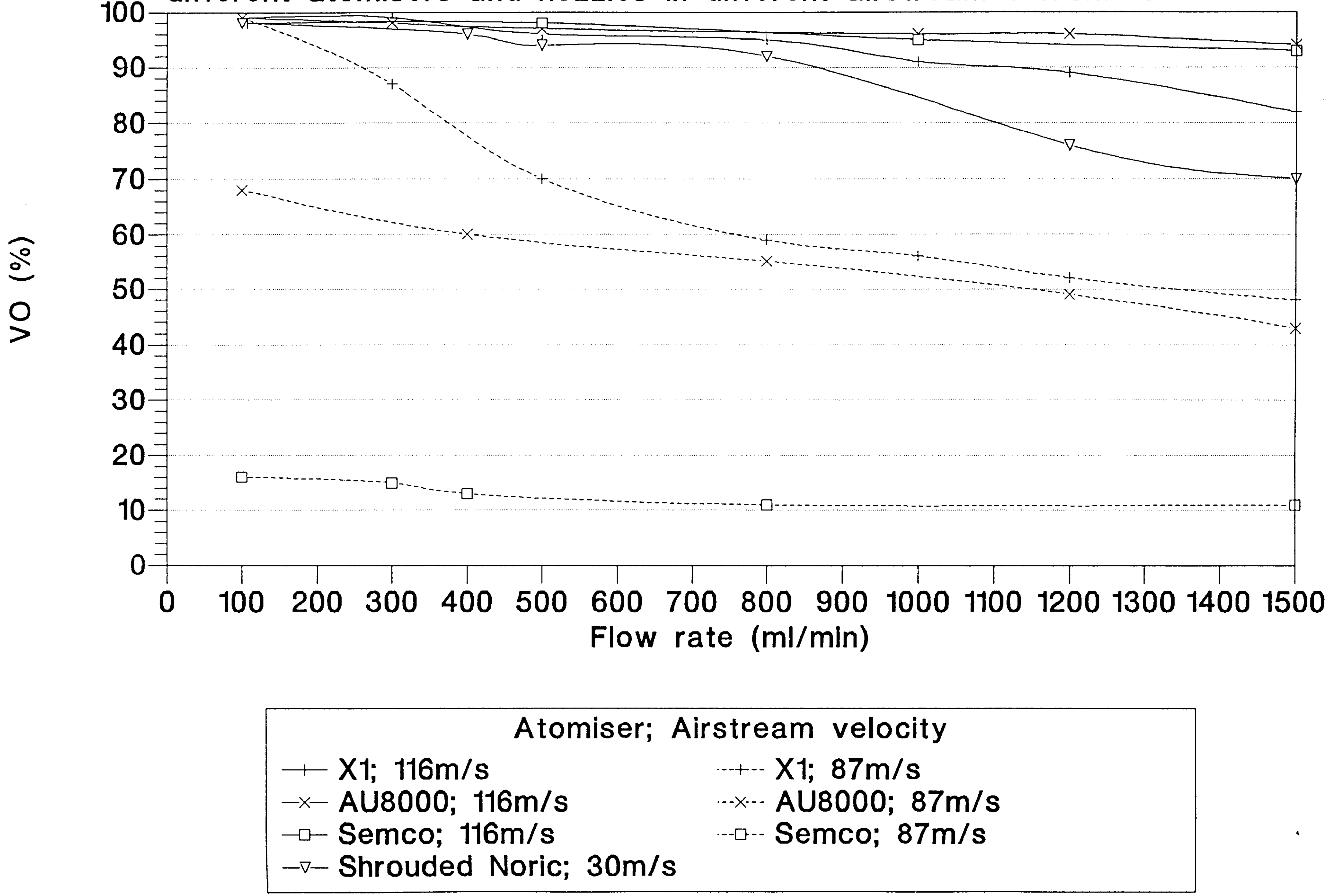


Fig 5.3. VO against flow rate of water+Agral sprayed through different atomisers and nozzles in different airstream velocities.



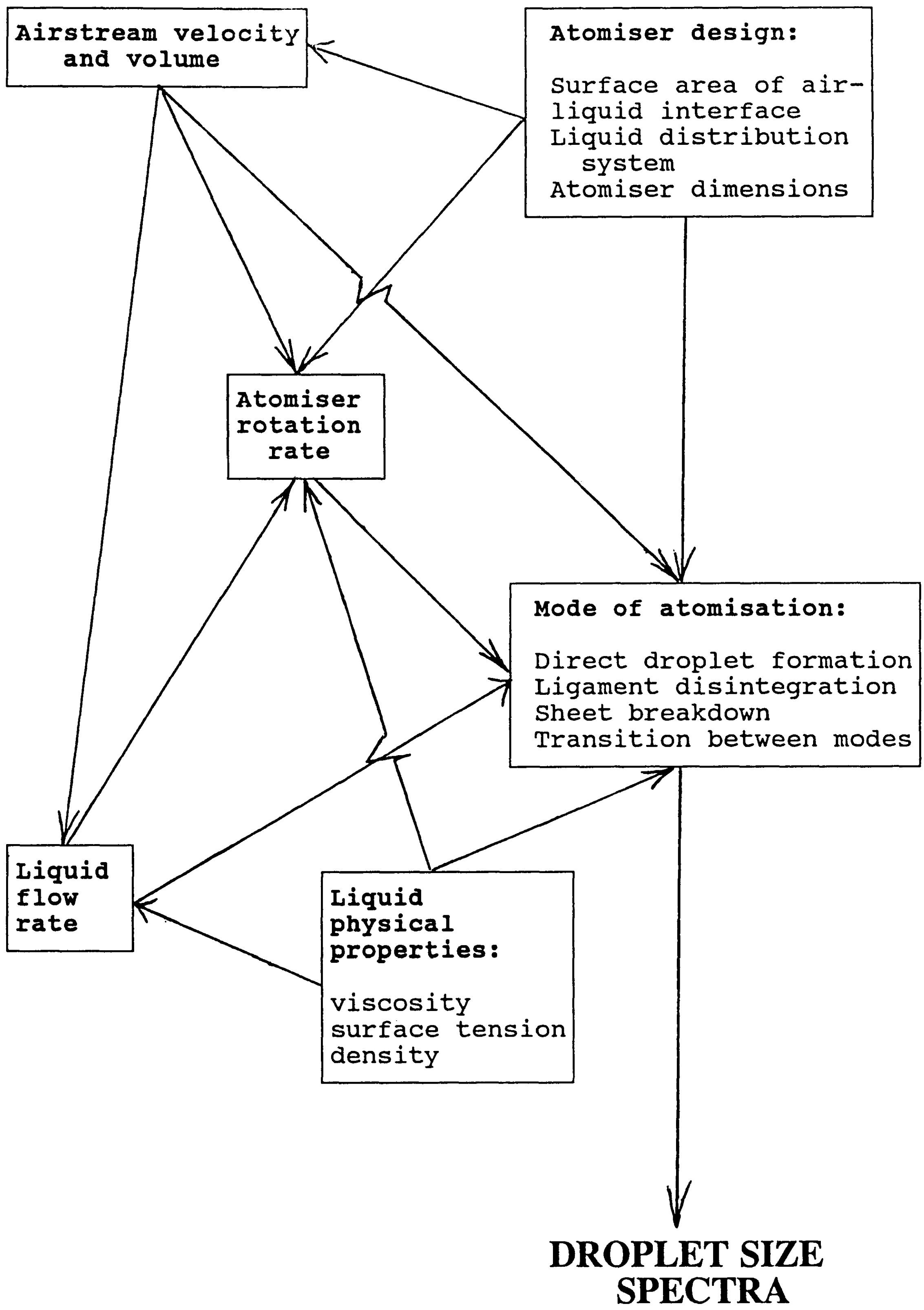
5.4. THE PREDICTION OF DROPLET SIZE SPECTRA FROM DIFFERENT ATOMISERS

This study has quantitatively evaluated the effects of changes in some liquid, airstream and atomiser characteristics upon the droplet size spectra produced by some air-assisted atomisers. It has been shown that the influence of these factors upon atomisation is complex because they are often dependant upon one-another. The interaction between factors is shown on Fig 5.4.

The VMD of a spray produced by these atomisers under given ranges of operational conditions and measured by Malvern laser droplet size analysers can be predicted using the models given in Chapter 3 ($r^2 \geq 0.89$).

When used in the field for the application of pesticides, an atomiser will usually be operated within certain fixed criteria. Liquid flow rate generally needs to be regulated within a relatively narrow range to deliver pesticide spray to a given area at a particular rate. Although it may be possible to alter flow rate by changing the forward speed of the sprayer, this may not be desirable. It is therefore often not practical to control droplet size by changing the flow rate. Liquid physical properties can also not be readily varied in the field. The operator is therefore only usually able to control droplet size by regulating the airstream velocity and the atomiser rotation rate. The value of U and N required to obtain a particular VMD at a given flow rate for a liquid with physical properties

Fig 5.4. The main factors which affect droplet size spectra produced by air-assisted rotary atomisers.



within the ranges involved in this study can be predicted using the equations given in Chapter 3, or using contour plots (Figs 5.5 to 5.11).

Droplet size spectra measurements obtained in the field using magnesium oxide slide sampling techniques were within similar ranges to those predicted by the empirical models developed from the laboratory droplet size values which were obtained using laser diffraction techniques. The field VMD values were slightly smaller than predicted due to evaporation effects.

Fig 5.5 Contour plot for predicting VMD from rotation rate and airstream velocity for water+Agral sprayed through X1 atomiser. Flow rate=300ml/min

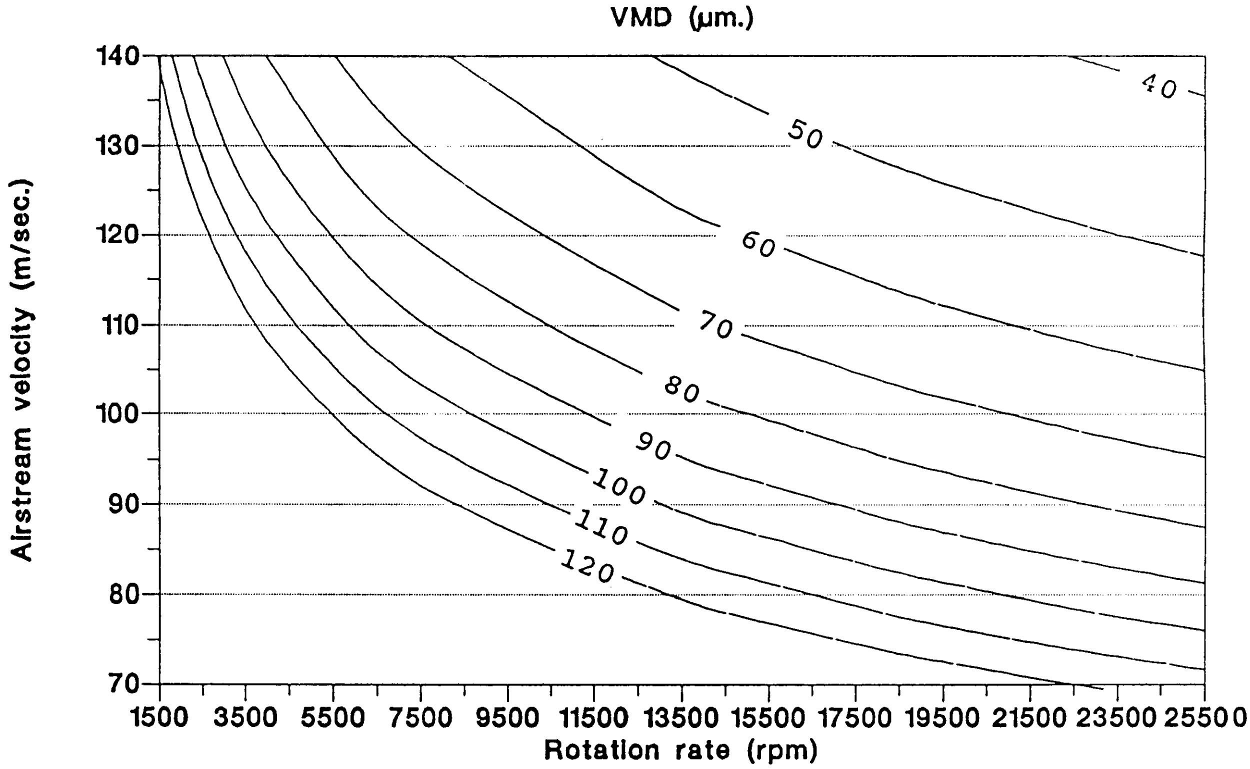


Fig 5.6 Contour plot for predicting VMD from rotation rate and airstream velocity for water+Agral sprayed through X1 atomiser. Flow rate=800ml/min

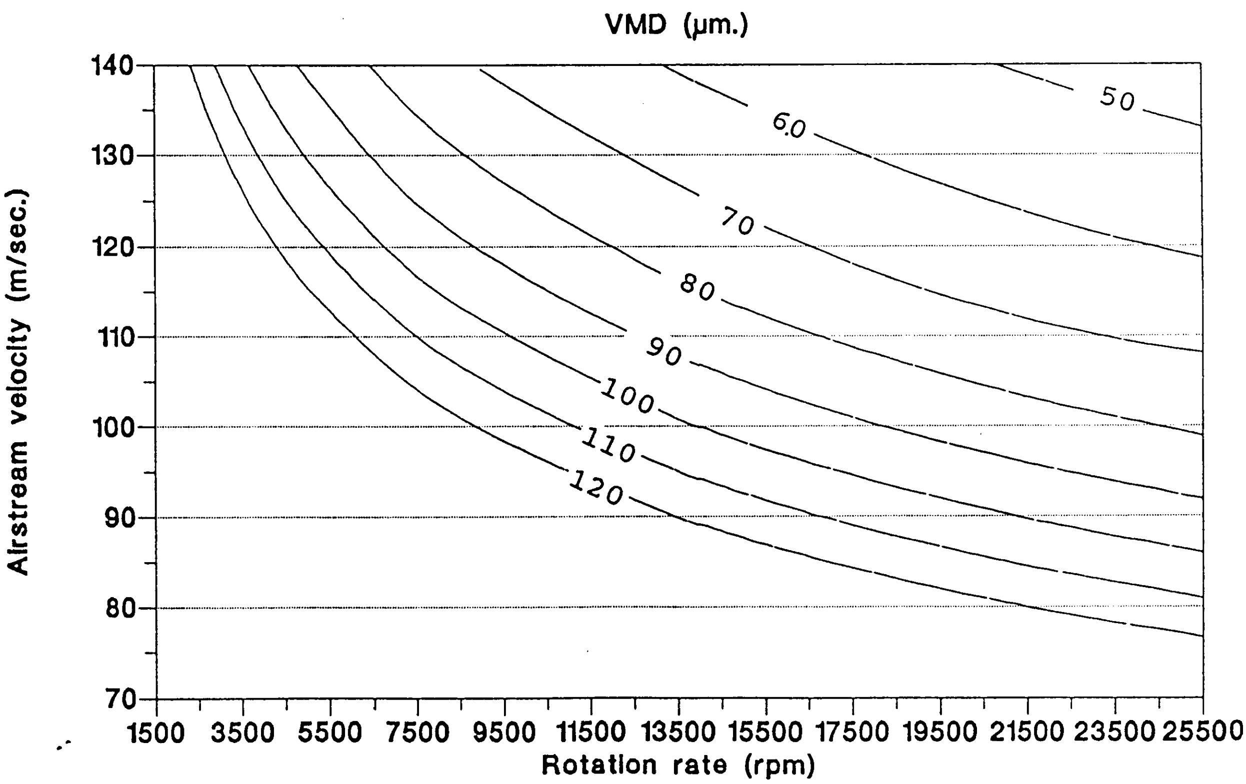


Fig 5.7 Contour plot for predicting VMD from rotation rate and airstream velocity for water+Agral sprayed through X1 atomiser. Flow rate=1500ml/min

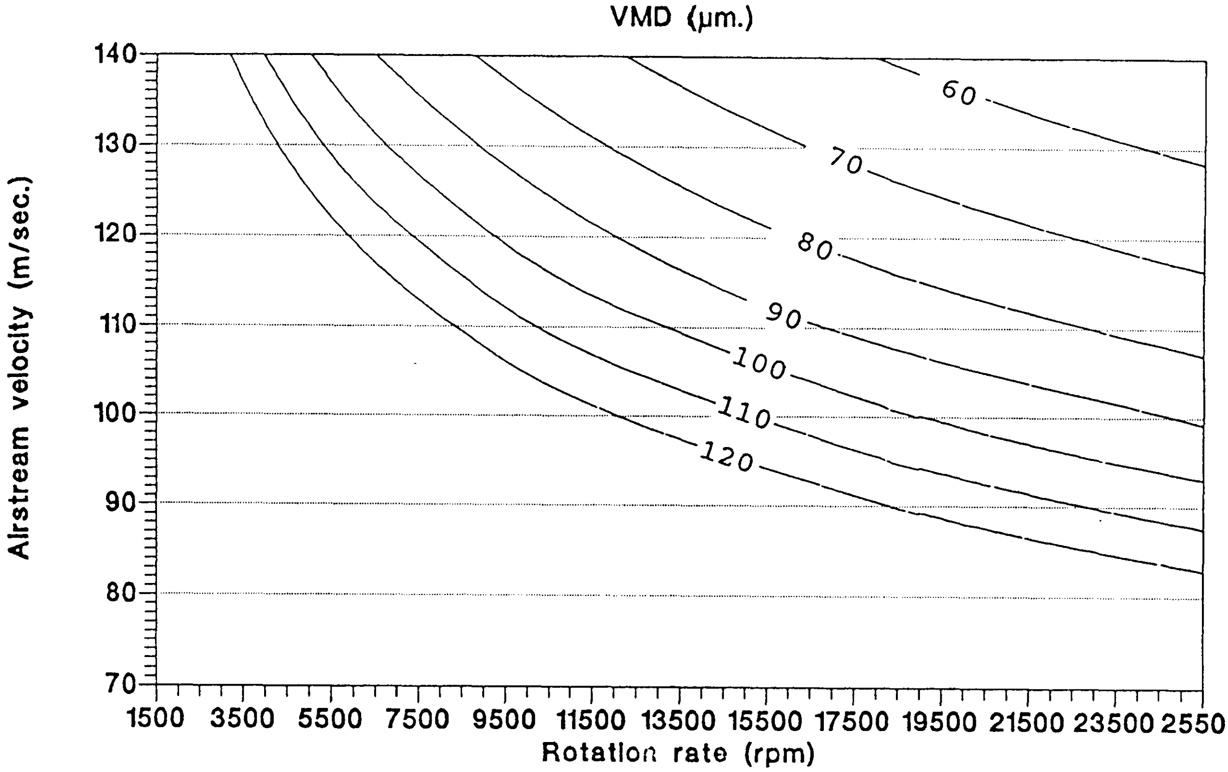


Fig 5.8 Contour plot for predicting VMD from rotation rate and airstream velocity for water+Agral sprayed through AU8000 atomiser.

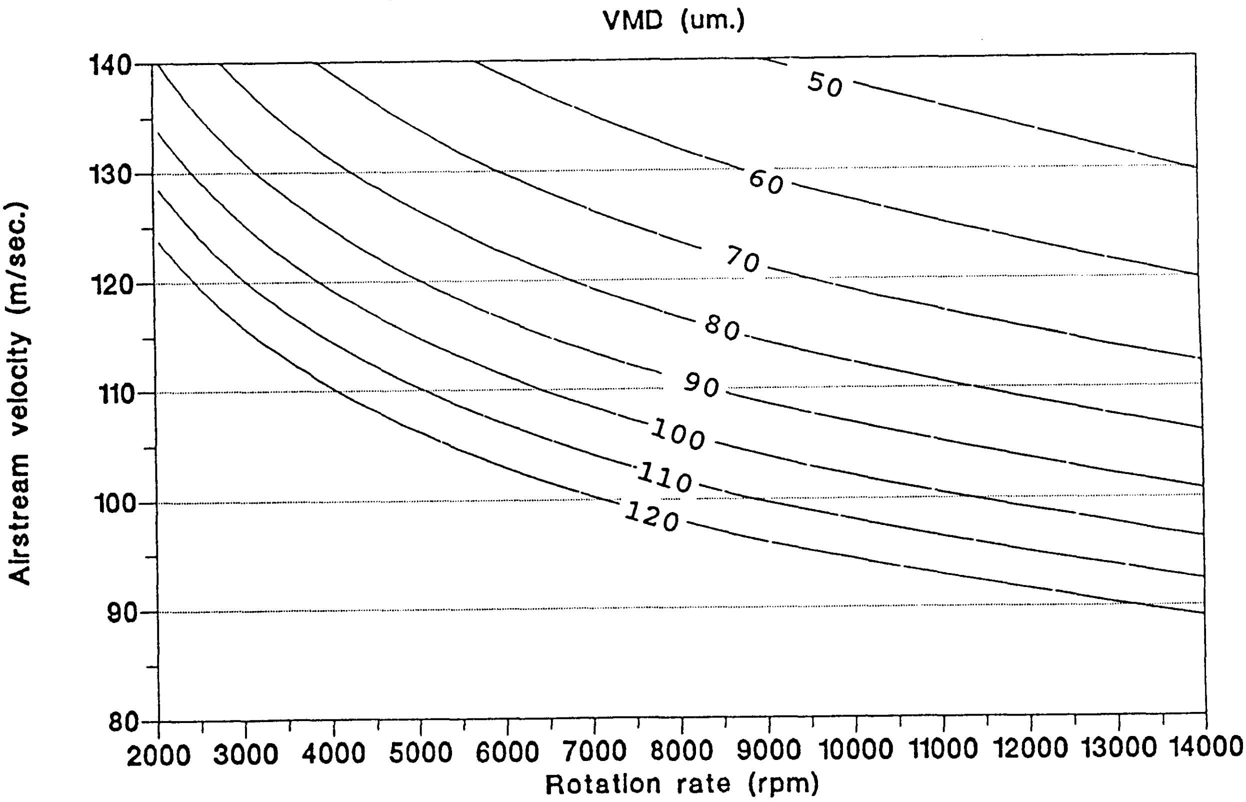


Fig 5.9 Contour plot for predicting VMD from rotation rate and airstream velocity for kerosene sprayed through AU8000 atomiser.

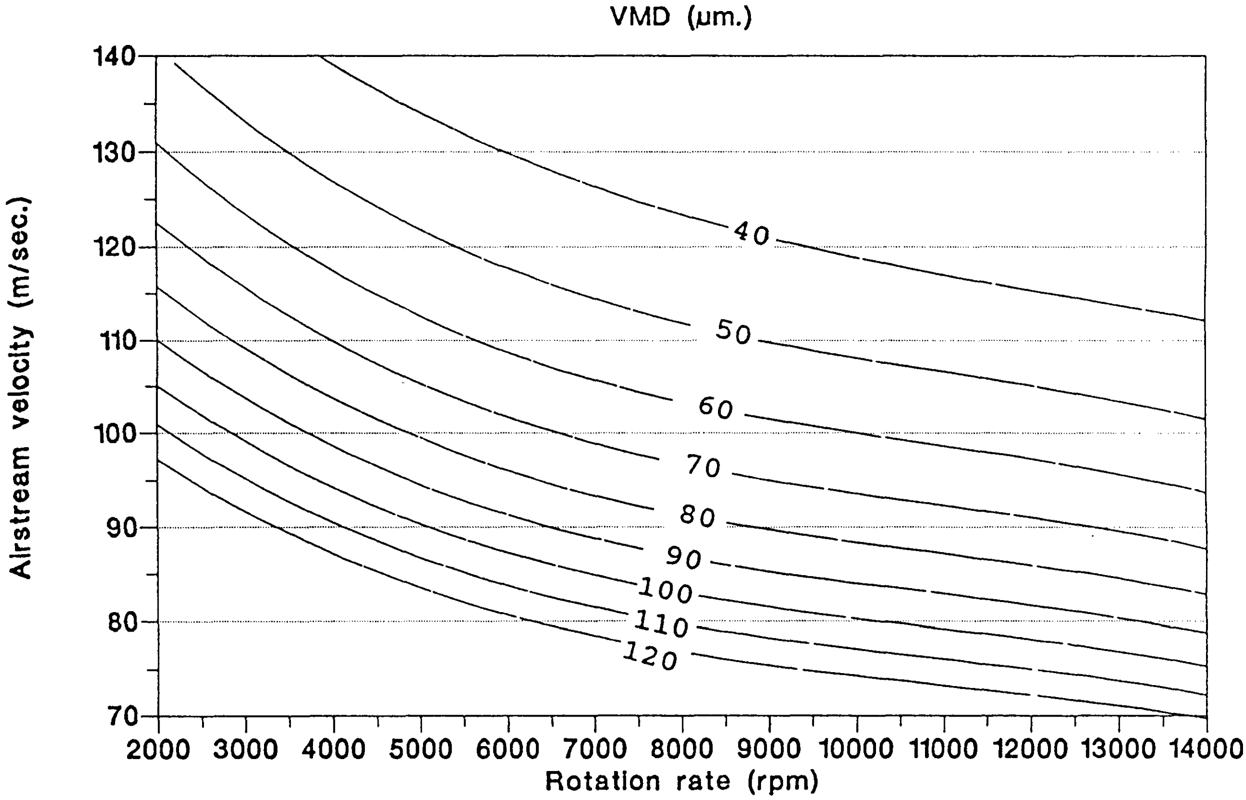


Fig5.10 Contour plot for predicting VMD from rotation rate and airstream velocity for Risella sprayed through AU8000 atomiser.

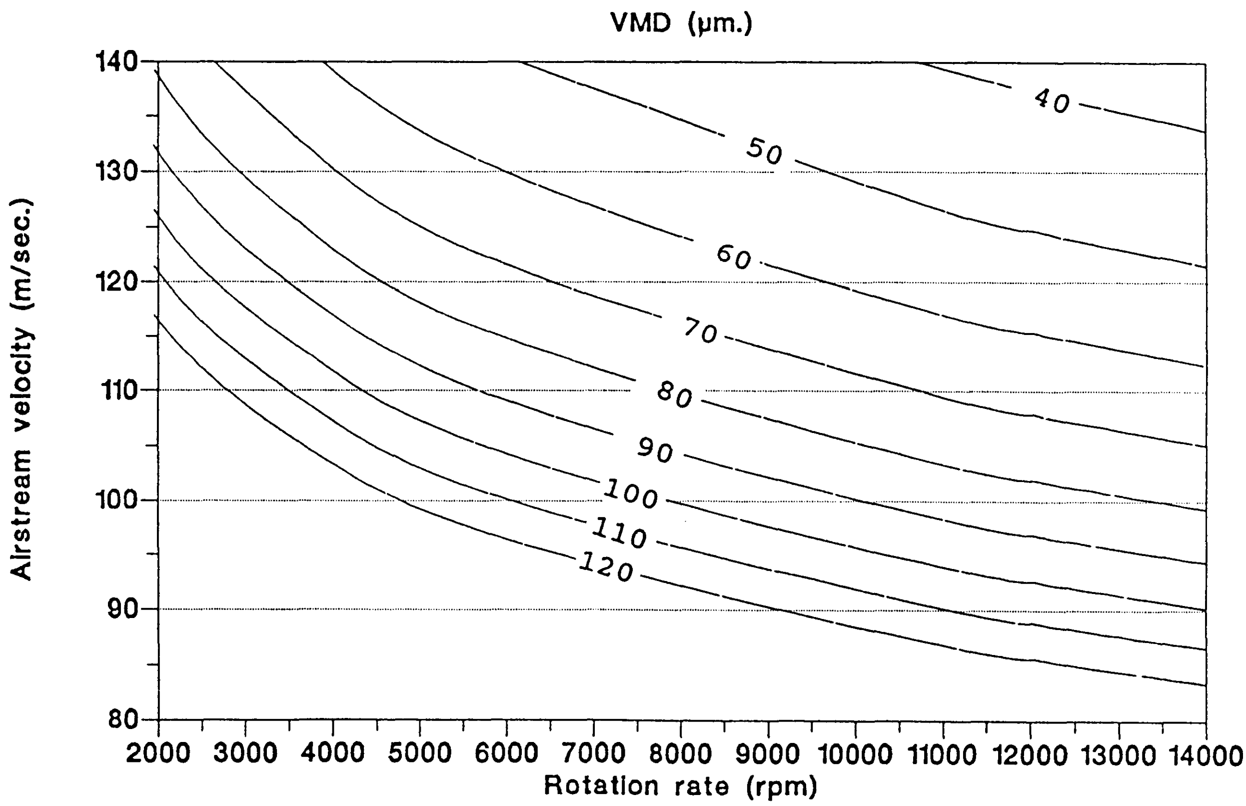
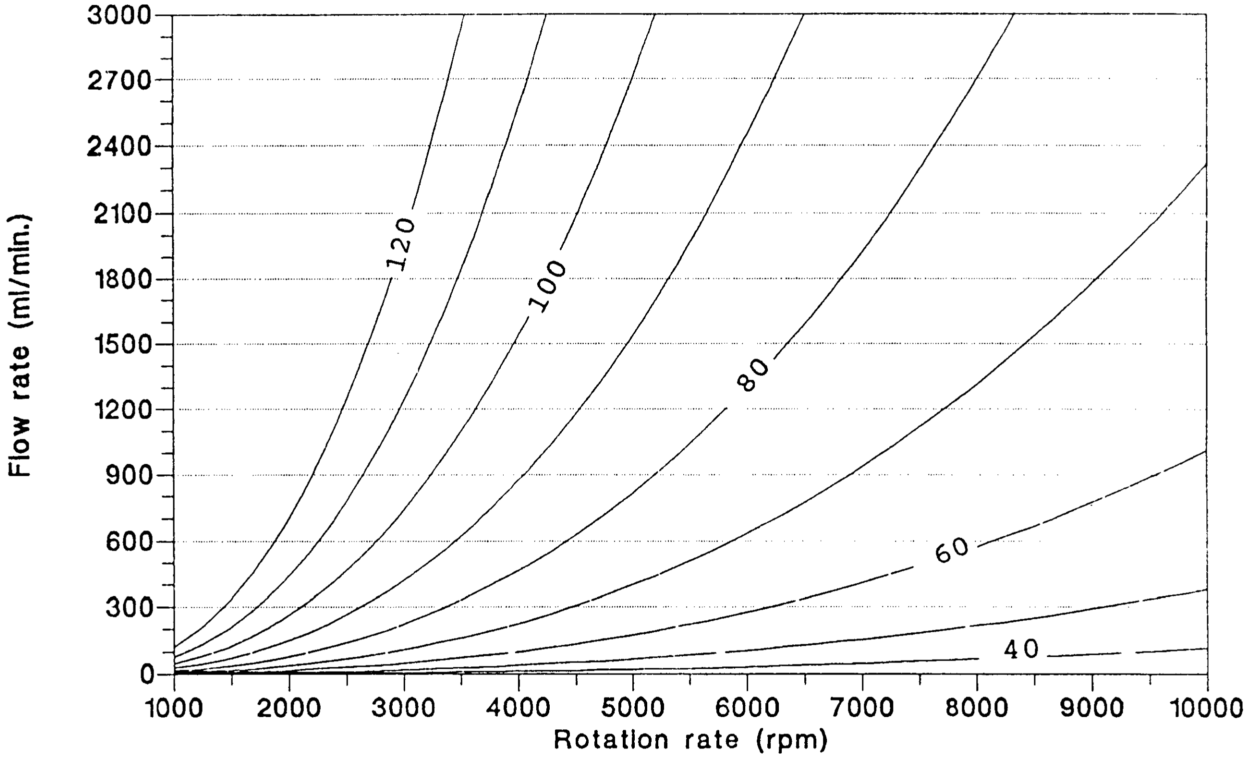


Fig5.11Contour plot for predicting VMD from rotation rate and
Flow rate for water+Agral sprayed through Noric atomisers.

VMD (um.)



5.5. THE VALUE OF AIR-ASSISTED ROTARY ATOMISERS FOR CONTROLLED DROPLET APPLICATION OF PESTICIDES

This study has shown that rotary atomisers can produce sprays with 99-100 % of the droplets having diameters of 40-100 μm. The droplet size spectra can be predicted and controlled by regulating flow rate, rotation rate and the airstream velocity.

The AU8000 rotary cage atomiser has been successfully used to control Spodoptera exempta by applying a pesticide spray with a VMD of 55 μm and NMD of 25 μm to the pest's habitat. This atomiser is robust, durable and easy to operate although it is also relatively expensive (Appendix 3).

The X1 atomiser has enabled application volumes for spraying grapefruit trees to be reduced when replacing hollow cone nozzles on axial fan sprayers. Although less robust than the AU8000, the X1 produced the narrowest droplet size spectra in this study at low cost (Appendix 3).

The Noric atomisers gave similar control over droplet size to the AU8000 but at lower cost. Although the Noric atomisers were not evaluated in the field, it is likely that the lack of bearings and sturdy fixing for the liquid tubes will cause them to have poor durability (Appendix 2).

Operator safety is important when assessing spraying equipment. The plastic air-shear, X1 and Noric atomisers did not cause operator injury if contacted. The metal AU8000 could cause slight injury if contacted. Burns could arise from operator contact with the unguarded exhausts on most motorised mist-blowers. Injury could also arise from unguarded recoil starters.

Chapter 6

CONCLUSIONS

6.1. INTRODUCTION

Conclusions drawn from the results of this study are separated into laboratory and field experiments.

6.2. LABORATORY STUDIES

1. The straight-jet air-shear type of nozzle used on most motorised knapsack mistblowers can produce droplets with diameter 40 to 100 μm, however the droplet size spectra are generally relatively wide, especially at airstream velocities below approximately 100 m/sec.

2. The AU8000 rotary cage and the X1 cupped spinning disc atomisers can be used to convert motorised knapsack mistblowers to achieve smaller droplets and narrower droplet size spectra than obtained with the air-shear nozzles.

3. In agreement with most previous studies with rotary atomisation, the VMD, VAD and VMD/NMD ratio of the sprays obtained with the atomisers in this study tended to increase with higher liquid flow rate, viscosity and surface tension, and with lower airstream velocity and

atomiser rotation rate. These factors were complexly inter-dependant. Atomiser rotation rate was dependant upon the liquid physical properties and flow rate; the airstream velocity; and the design of the atomiser.

The percentage volume of droplets occuring within the size band 40 to 100 μm, considered most suitable for the control of Spodoptera exempta larvae, decreased with higher liquid flow rate, viscosity and surface tension, and with higher airstream velocity and rotation rate.

4. The addition of external air-assistance effectively reduced the dependence of the droplet size spectra produced by the rotary atomisers upon liquid flow rate and atomiser rotation rate.

5. Empirical models developed to predict the VMD for atomisers involved in this study were more accurate than similar models developed to predict VAD and VMD/NMD ratio because numeric droplet size distribution data is derived with less accuracy than volumetric data using Malvern PSA instruments. The power indices derived for the VMD models in this study were generally within similar ranges to those given by most previous studies with rotary and air-assisted atomisers.

6. The effects of liquid density and the mesh size of the AU8000 rotary cage atomiser gauze could not be accurately incorporated into models for predicting droplet size spectra parameters.

7. The Noric slotted rotary drum atomisers produced lower or equal VMD/NMD ratios when the drums were rotating in the same direction as the vanes. This was due mainly to the relatively larger axial airstream velocity generated and the spreading of liquid across the inner vane surfaces when drums rotated in the vane direction.

8. The addition of peripheral teeth to the vanes of a Noric drum caused a reduction in VMD/NMD ratio because the teeth acted as 'zero' issuing surfaces for the formation of relatively narrow liquid ligaments.

9. The addition of grooves to the inner vane surfaces of toothed vanes on Noric drums caused a reduction in VMD by channelling liquid more evenly to the 'zero' issuing surfaces.

10. Differences observed in droplet size spectra when the liquid injector in a Noric drum was placed at different positions relative to a shroud window increased with a higher liquid flow rate. The lowest VMD and VMD/NMD ratio values were obtained when the drum was shrouded at the injector side.

6.3. FIELD STUDIES

1. Droplet densities on vertical paper targets within grass and maize canopies were up to four times greater than on horizontal targets.

2. The VMD and NMD values obtained during field trials with the AU8000 atomiser fitted to a motorised knapsack mistblower were similar to those obtained with this atomiser during the laboratory studies.

3. There was a close correlation between the density of droplets on paper targets and the mortality of Spodoptera exempta larvae.

4. Field trials indicated that a minimum of approximately 9 droplets of a 2.4 % ULV formulation of cypermethrin would be required per square centimetre to achieve 50 percent larval kill (LN_{50}). 95 percent mortality (LN_{95}) would require approximately 28 droplets/cm^2. The biocidal area was approximately 4.5 mm^2.

5. Suitable track spacings to achieve LN_{50} were estimated to be 25 and 45 m respectively for back-mounted and vehicle-mounted mistblowers in windspeeds of up to 2m/sec. This is greater than the 10 to 15 m swath widths previously obtained with "Micro-Ulva" sprayers.

6. In this report, the effect of droplet density upon control of Spodoptera exempta larvae has been studied. The

effect of droplet size independant of density should be studied in the laboratory and field to determine the biologically optimum droplet size.

7. Improved spray coverage in grapefruit tree canopies was achieved at reduced volume application rates when the hollow cone ceramic nozzles on an axial fan sprayer were replaced with X1 atomisers. There was also a 70 percent reduction in the total volume of liquid lost to the ground beneath trees. These improvements were due to a reduction in the VMD from approximately 465 to 67 μm using the X1 atomisers.

6.4. COMPARISON BETWEEN ROTARY ATOMISERS

1. The Micron X1 cupped spinning disc atomiser had advantages because it could produce relatively small droplets in a narrow spectrum compared to the other atomisers at flow rates from 100 to 1500 ml/min, in airstreams with velocity up to 116 m/sec; it was available at relatively low cost; and was easy to use. Although it would be relatively easily damaged under rough field use, replacement components were available at low cost.

2. The AU8000 rotary cage atomiser enabled the VMD and VMD/NMD ratio produced by air-shear straight jet mistblower nozzles to be reduced. It was considered to be easy and very robust for field use. The main disadvantages of the AU8000 atomiser were its relatively high cost and high weight compared to the Micronex.

3. The Noric slotted rotary drum atomisers had the advantage of generating their own axial airstream which assisted the atomisation and subsequent projection of liquid sprays. The droplet size spectra were similar to those of the AU8000 atomiser. Noric atomisers were considered easy to use and are likely to be available at similar cost to the X1 atomiser. They are unlikely to be as durable as the X1 and AU8000 atomisers.

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Appendix 1

FIELD TRIAL SITES AND EXPERIMENTAL CONDITIONS

Date:	7 April 1990
Location:	Seme Kakelo, near Kisumu.
Crop:	Maize
Sprayer:	Solo/AU8000
Chemical:	Cypermethrin 2.4 % ULV
Walk line:	85 m
Sample line:	60 m
Flowrate:	230 ml/min
Dosage Rate:	0.9 l/ha
Start time:	15:12.00
Stop time:	15:13.57
Cloud cover:	less than 1/8
Windspeed:	1-2 m/sec., average 1.5m/sec.
Wind direction	Southerly
W displacement	0 deg.
Air temp.:	28.3 C
Rel. humidity:	72 %
Atomiser height	1 m. (Horizontal).
Crop height:	25cm. max.
Larval stage:	2-4

Date:	9 April 1990
Location:	Seme Kakelo, near Kisumu.
Crop:	Maize
Sprayer:	Solo/AU8000
Chemical:	Cypermethrin 2.4 % ULV
Walk line:	70 m
Sample line:	90 m
Flowrate:	190 ml/min
Dosage Rate:	1.0 l/ha
Start time:	15:25.12
Stop time:	15:26.49
Cloud cover:	less than 1/8
Windspeed:	1-2 m/sec., average 1.5m/sec.
Wind direction	Southerly
W displacement	0 deg.
Air temp.:	27.8 C
Rel. humidity:	71 %
Atomiser height	1 m. (Horizontal).
Crop height:	35cm. max.
Larval stage:	3-4

Date:	10 April 1990
Location:	Seme Kambewa, near Kisumu.
Crop:	Maize and mud.
Sprayer:	AU8000
Chemical:	Cypermethrin 2.4% ULV.
Walk line:	75m
Sample line:	90m.
Flowrate:	354ml/min.
Dosage Rate:	440ml/0.4ha. = 1.1l/ha.
Start time:	11:45.30
Stop time:	11:46.54
Windspeed:	approx. 1m/sec.
Wind direction	0 deg.
W displacement	approx. 5 deg.
Air temp.:	26.2 C
Rel. humidity:	70 %
Atomiser height	1 m. (Horizontal).
Crop height:	apprx. 25cm.
Larval stage:	2-3

Date:	18 April 1990
Location:	119 Masai Rd. West, Langata, NBI.
Crop:	Range/Pasture grass.
Sprayer:	Vehicle-mounted AU8000.
Chemical:	Cypermethrin 2.4% ULV.
Walk line:	50m
Sample line:	90m
Treated area:	1.0 ha
Flowrate:	140ml/min
Dosage Rate:	0.9 l/ha
Start time:	16:51.00
Stop time:	16:52.55
Cloud cover:	1/8
Windspeed:	2m/sec
Wind direction	0 deg
W displacement	0 deg. (perfect).
Air temp.:	21.4 C
Rel. humidity:	60 %
Atomiser height	2 m.
Crop height:	apprx. 25cm.
Larval stage:	2-3

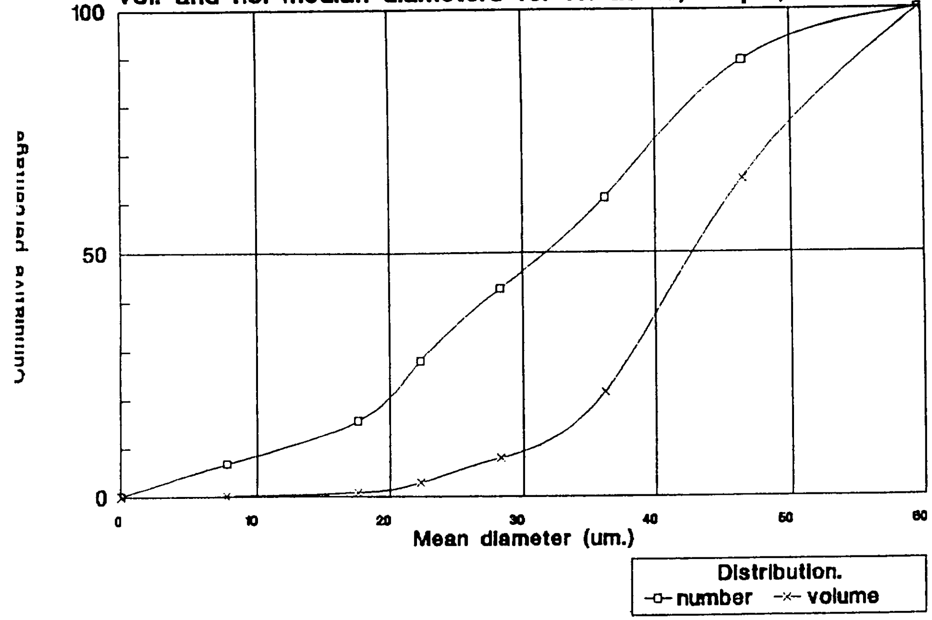
Date:	19 April 1990
Location:	119 Masai Rd. West, Langata, NBI.
Crop:	Range/Pasture grass.
Sprayer:	AU8000
Chemical:	Cypermethrin 2.4% ULV.
Walk line:	160m
Sample line:	85m
Flowrate:	230ml/min.
Dosage Rate:	710ml/0.8ha = approx. 0.9l/ha.
Start time:	16:30.00
Stop time:	16:33.07
Cloud cover:	nil
Windspeed:	1-3m/sec., average 2m/sec.
Wind direction	5 deg.
W displacement	5 deg.
Air temp.:	23.6 C
Rel. humidity:	55 %
Atomiser height	1 m. (Horizontal).
Larval stage:	2-3

Date:	19 April 1990
Location:	119 Masai Rd. West, Langata, NBI.
Crop:	Range/Pasture grass.
Sprayer:	AU8000
Chemical:	Cypermethrin 2.4% ULV.
Walk line:	160m
Sample line:	85m
Flowrate:	230ml/min.
Dosage Rate:	0.9 l/ha
Start time:	16:30.00
Stop time:	16:33.07
Cloud cover:	nil
Windspeed:	2 m/sec.
Wind direction	0 deg.
W displacement	5 deg.
Air temp.:	23.6 C
Rel. humidity:	55 %
Atomiser height	1 m. (Horizontal).
Crop height:	5 to 25cm.
Larval stage:	2-3

Appendix 2

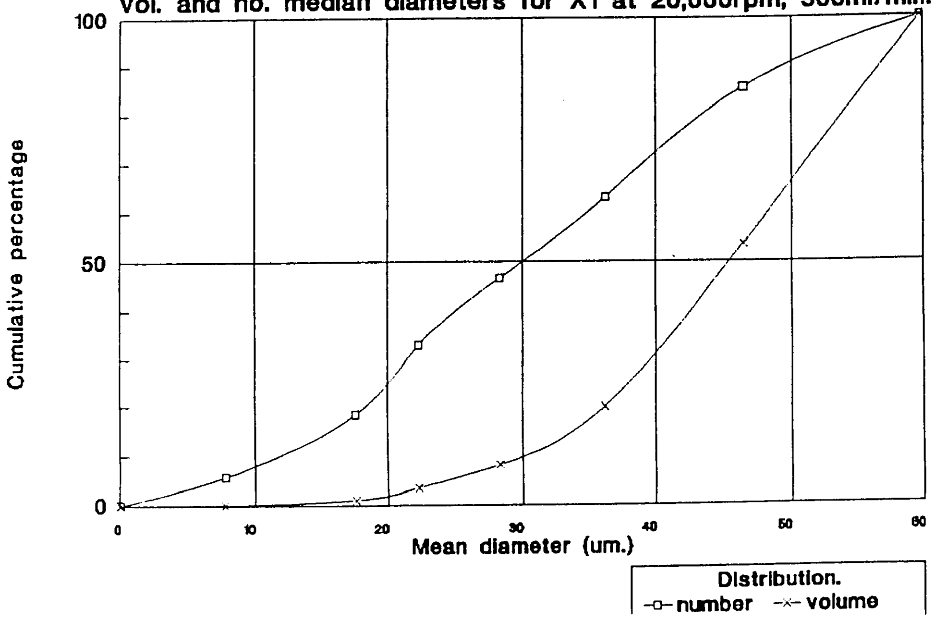
FIELD TRIAL DROPLET SIZE SPECTRA

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 300ml/min.

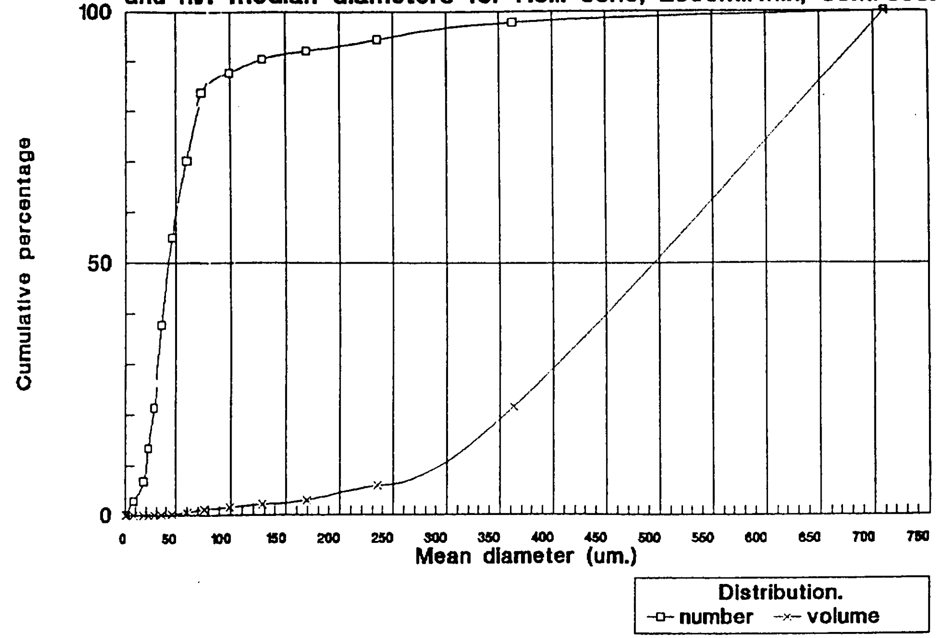


VMD=43 NMD=32; VMD/NMD=1.3

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 500ml/min.

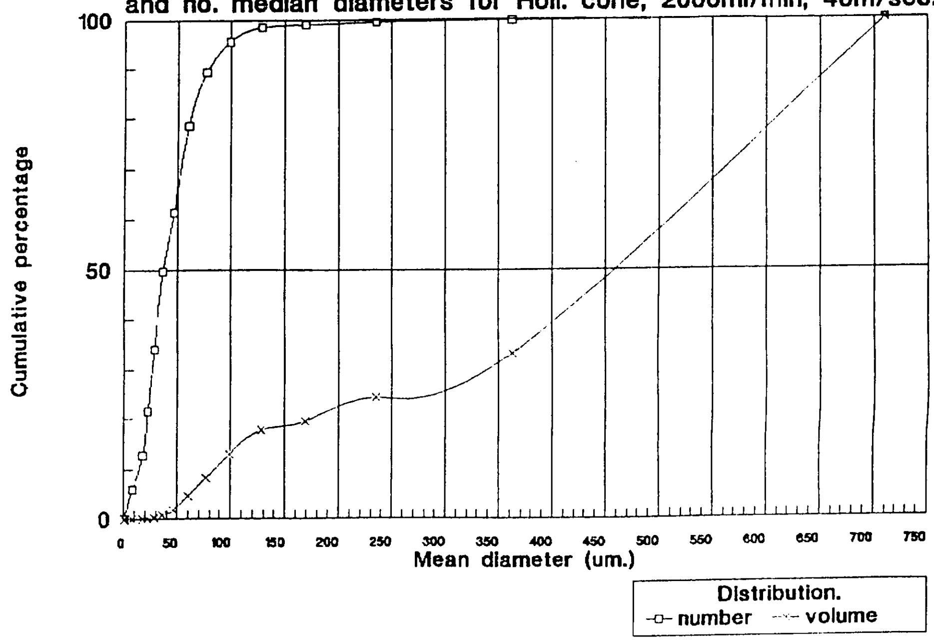


Mean drop size against cumulative percentage to calculate vol. and no. median diameters for Holl. cone, 2000ml/min, 60m/sec.

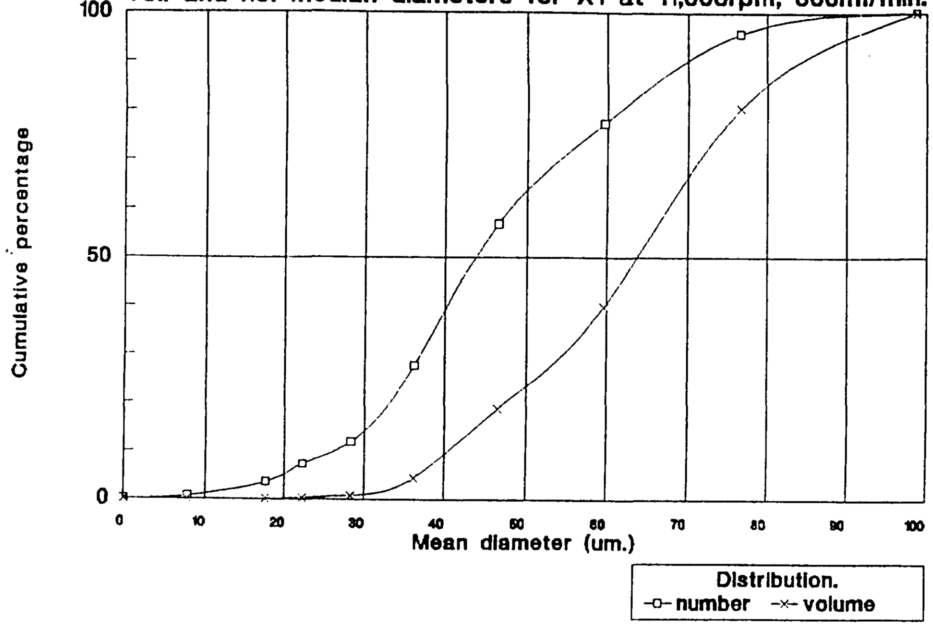


VMD=498 NMD=43; VMD/NMD=12

Mean drop size against cumulative percentage to calculate vol. and no. median diameters for Holl. cone, 2000ml/min, 40m/sec.

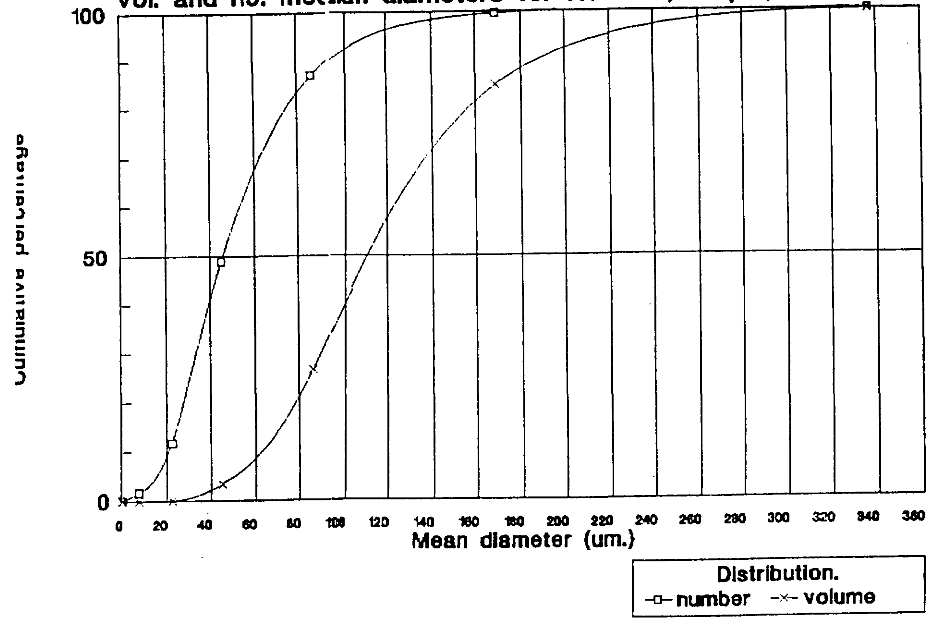


Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 11,000rpm, 300ml/min.



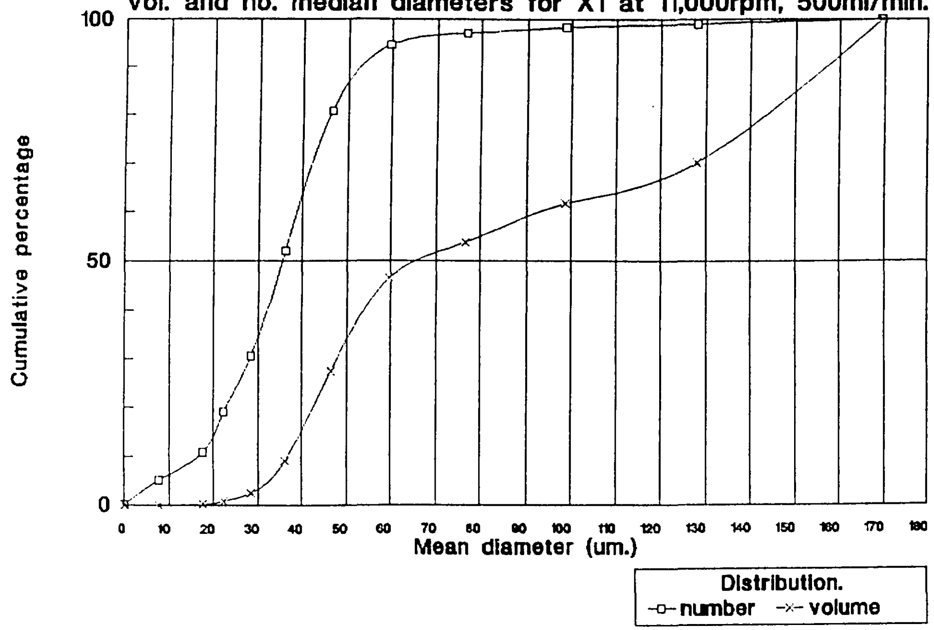
VMD=63 NMD=44; VMD/NMD=1.4

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 11,000rpm, 850ml/min.



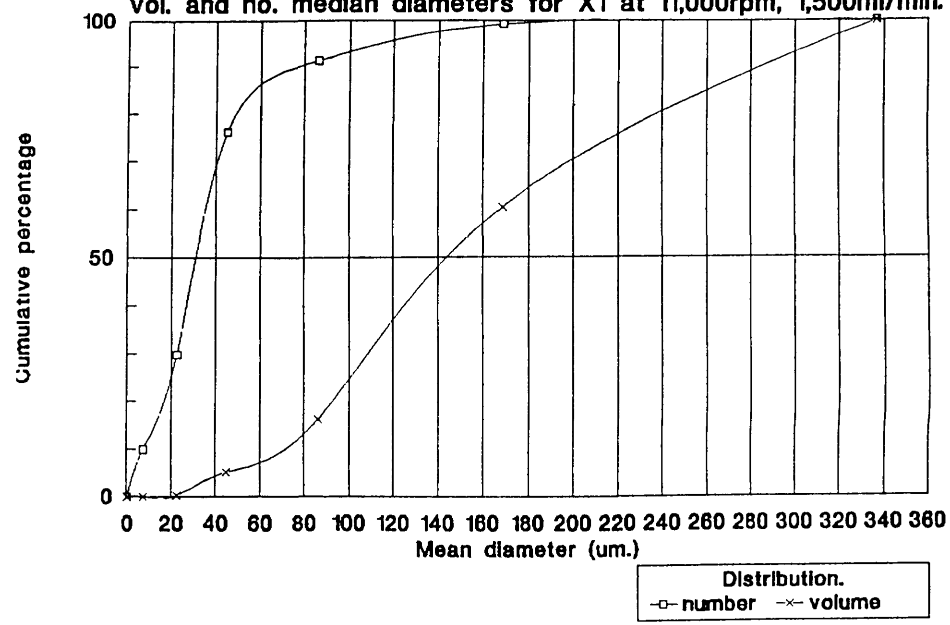
VMD=110 NMD=48; VMD/NMD=2.3

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 11,000rpm, 500ml/min.

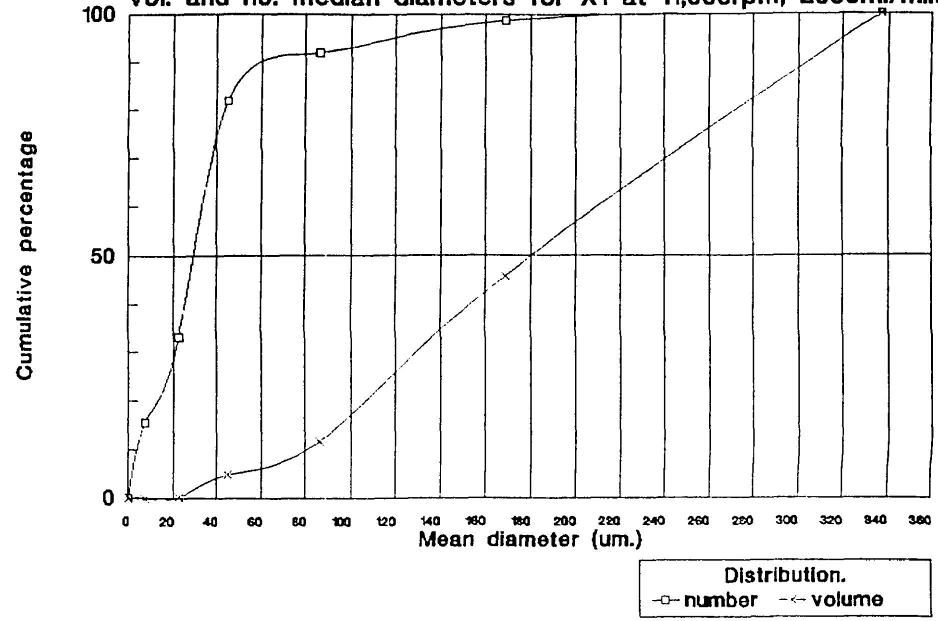


VMD=66 NMD=37; VMD/NMD=1.8

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 11,000rpm, 1,500ml/min.

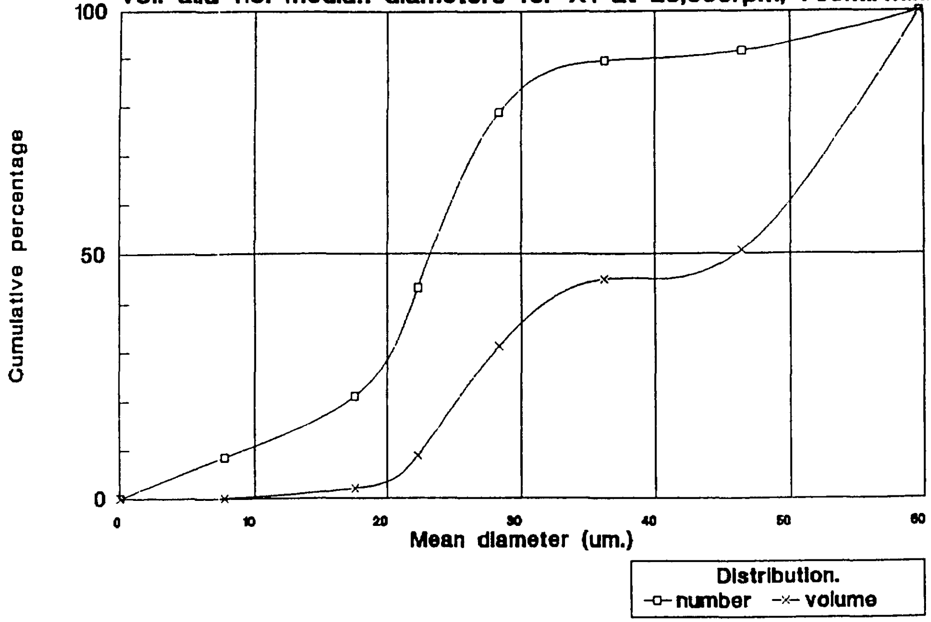


Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 11,000rpm, 2000ml/min.



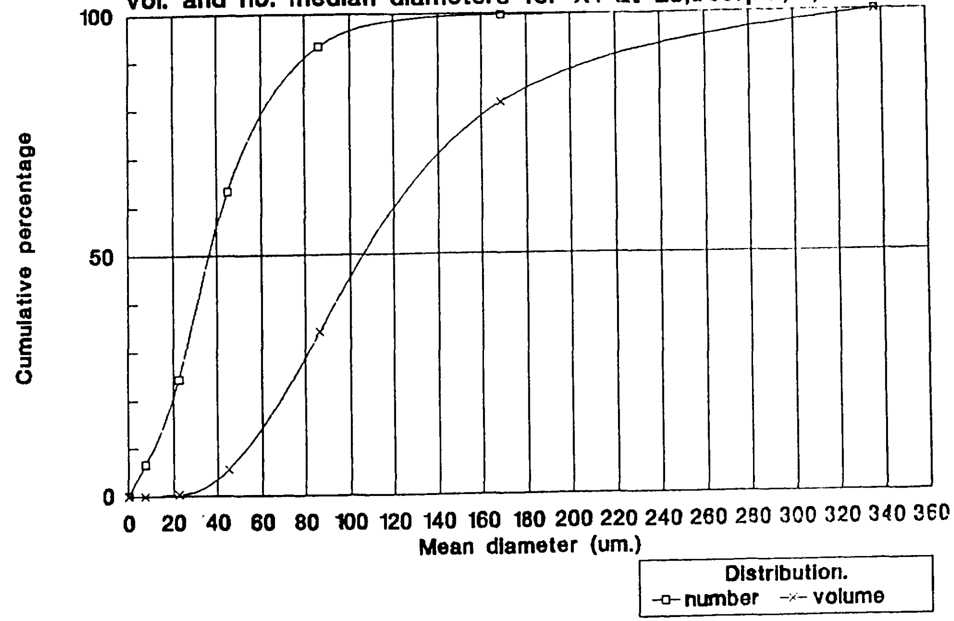
VMD=180 NMD=29; VMD/NMD=6.2

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 700ml/min.



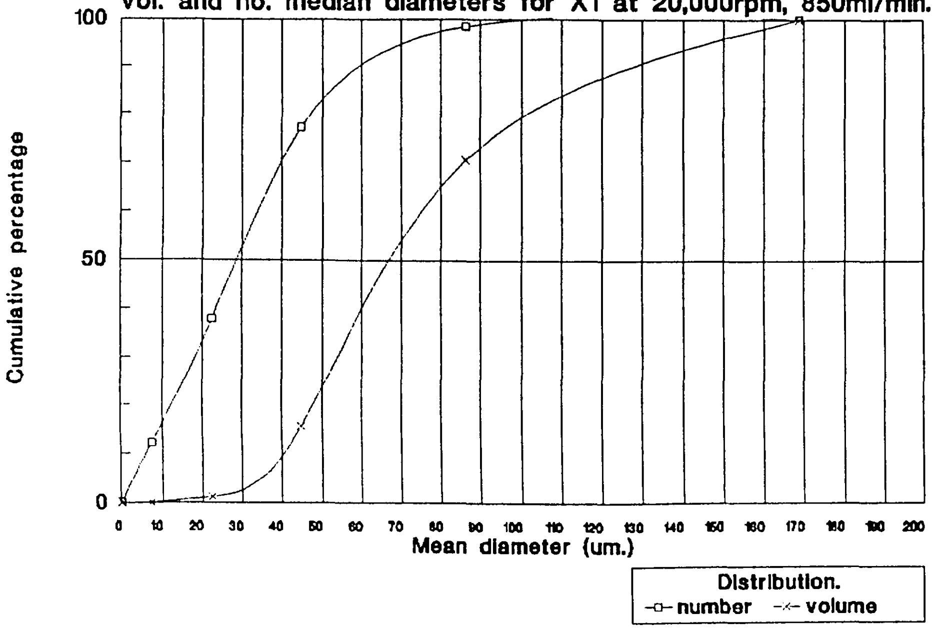
VMD=47 NMD=23; VMD/NMD=2.0

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 1,500ml/min.



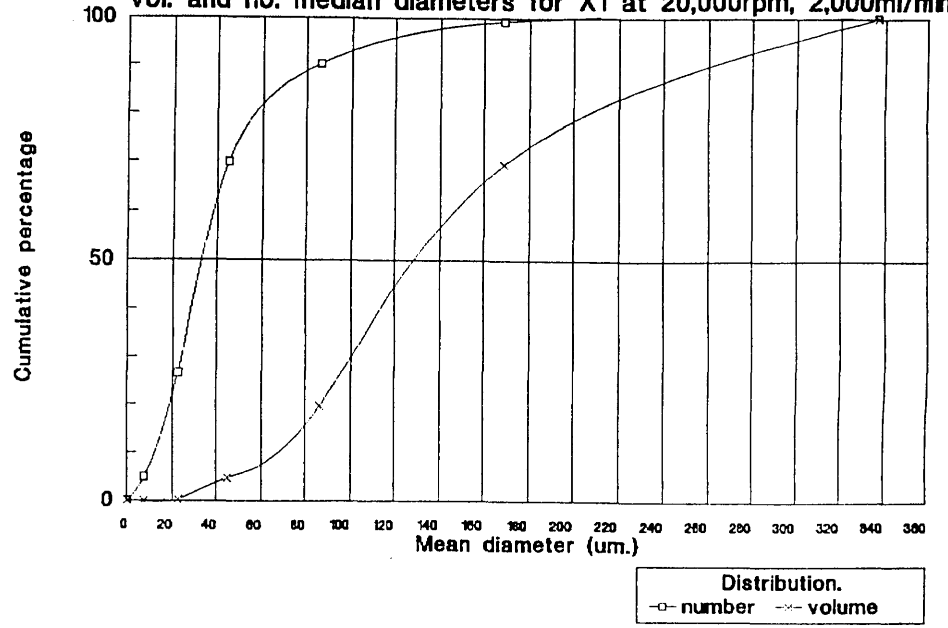
VMD=107 NMD=28; VMD/NMD=3.8

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 850ml/min.

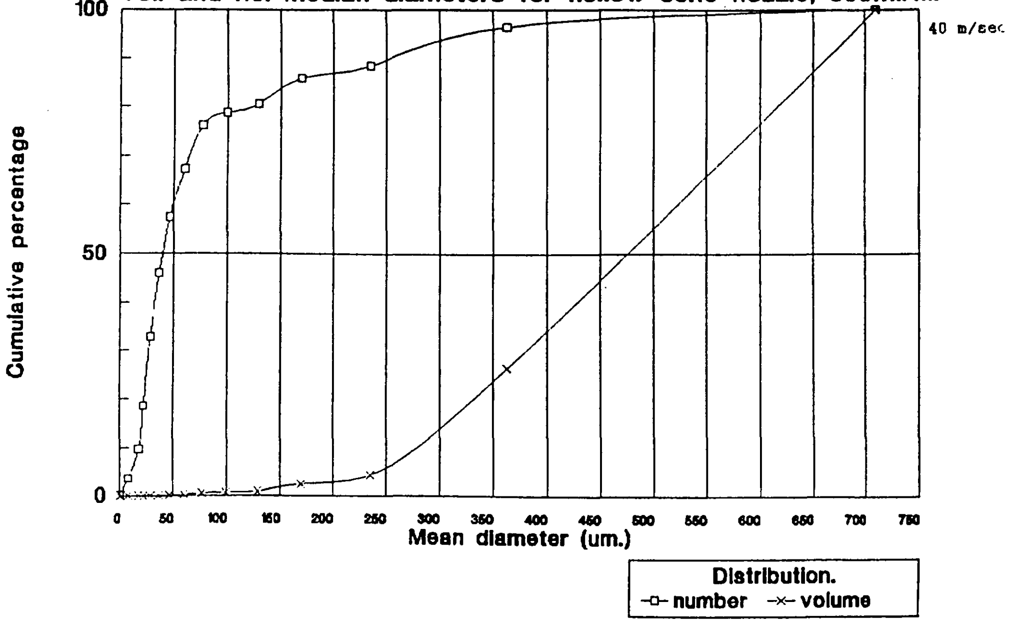


VMD=87 NMD=29; VMD/NMD=2.3

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for X1 at 20,000rpm, 2,000ml/min

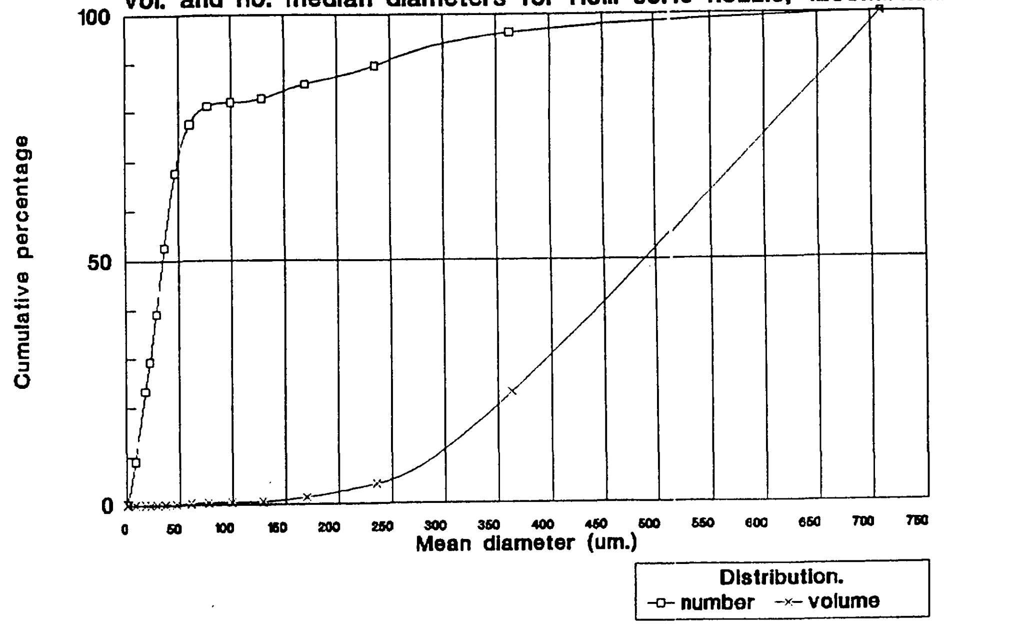


Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for hollow cone nozzle, 500ml/mi



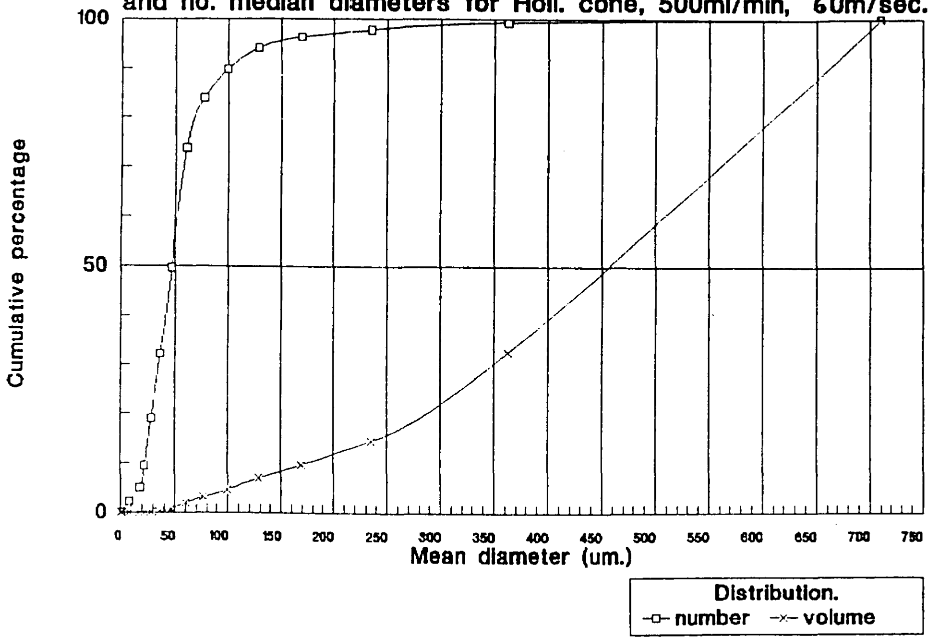
VMD=475 NMD=40; VMD/NMD=11.9

Mean droplet size against cumulative percentage to calculate vol. and no. median diameters for Holl. cone nozzle, 1200ml/min. 40 m/sec



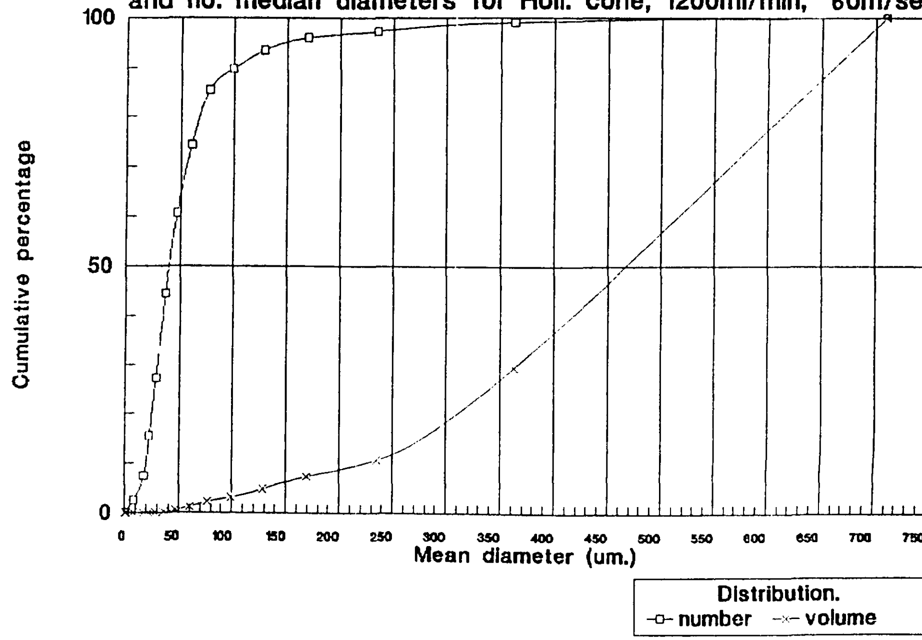
VMD=487 NMD=35; VMD/NMD=13.9

Mean drop size against cumulative percentage to calculate vol and no. median diameters for Holl. cone, 500ml/min, 60m/sec.



VMD=456 NMD=49; VMD/NMD=9.3

Mean drop size against cumulative percentage to calculate vol and no. median diameters for Holl. cone, 1200ml/min, 60m/sec.



VMD=468 NMD=39; VMD/NMD=12

DROPLET COVERAGE ON TARGETS WITHIN TREE CANOPIES

The percentage droplet cover of water-sensitive paper targets and leaves collected from different parts of the tree canopy for each trial are shown in the following tables.

<u>Coverage of trees with droplets using X1 atomiser.</u>
<u>Application rate = 6 l/tree.</u>

Percentage Coverage with spray

1. Unpruned side

Tree 1			Tree 2			Tree 3			Mean		
40	70	90	50	60	70	80	70	80	57	67	80
40	50	100	60	70	50	80	70	80	60	63	77
50	70	60	60	80	70	90	80	80	67	77	70

2. Pruned side

70	70	80	80	80	90	80	80	70	77	77	80
80	80	90	90	90	90	70	80	70	80	83	83
50	60	50	70	90	90	80	70	80	67	73	73

3. Inner tree

60	70	90	80	80	80	80	80	80	73	77	83
70	80	80	80	90	80	80	80	90	77	83	83
50	70	60	80	80	80	90	80	90	73	77	77

4. Trunk

	F	NF	F	NF	F	NF	Mean F	Mean NF
5m.	50	50	60	50	70	60	60	53
3m.	60	40	50	50	50	40	53	43
1m.	50	20	40	30	50	40	47	30
.3m.	60	30	50	40	50	40	53	37

F= Trunk facing spray; NF= Trunk not facing spray.

<u>Coverage of trees with droplets using X1 atomiser.
Application rate = 12.5 l/tree.</u>

Percentage Coverage with spray.

1. Unpruned side

Tree 1			Tree 2			Tree 3			Mean		
90	100	100	100	90	90	100	90	100	97	93	97
100	80	100	100	100	100	100	100	100	100	93	100
100	80	100	100	100	100	90	100	100	97	93	100

2. Pruned side

90	100	90	100	90	100	100	90	100	97	93	97
100	100	100	100	90	100	100	100	100	100	97	100
100	90	100	100	100	100	90	100	100	97	97	100

3. Inner tree

90	90	100	100	90	90	100	100	100	97	93	97
80	80	70	100	100	100	100	100	100	93	93	90
90	90	90	100	100	100	100	100	100	97	97	97

4. Trunk

	F	NF	F	NF	F	NF	Mean F	Mean NF
5m.	80	80	80	80	90	90	83	83
3m.	90	80	100	90	100	100	97	90
1m.	90	90	90	90	100	90	93	90
.3m.	70	70	100	100	100	100	90	90

F= Trunk facing spray; NF= Trunk not facing spray.

Coverage of trees with droplets using X1 atomiser.
Application rate = 25 l/tree.

Percentage Coverage with spray.

1. Unpruned side

Tree 1			Tree 2			Tree 3			Mean		
100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100

2. Pruned side

100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100

3. Inner tree

100	100	90	100	100	100	100	100	100	100	100	97
100	100	100	100	90	100	100	100	100	100	97	100
100	100	100	100	100	100	100	100	100	100	100	100

4. Trunk

	F	NF	F	NF	F	NF	Mean F	Mean NF
5m.	100	100	100	100	100	100	100	100
3m.	100	100	100	100	100	100	100	100
1m.	100	100	100	100	100	100	100	100
.3m.	100	100	100	100	100	100	100	100

F= Trunk facing spray; NF= Trunk not facing spray.

Coverage of trees with droplets using hollow cone nozzles. Application rate = 12.5 l/tree.

Percentage Coverage with spray.

1. Unpruned side

Tree 1			Tree 2			Tree 3			Mean		
70	70	80	60	60	60	50	70	60	60	67	67
80	80	70	70	60	80	70	70	70	73	70	73
90	90	80	90	90	80	80	80	100	87	87	87

2. Pruned side

60	70	70	70	70	70	60	70	70	63	70	70
80	80	90	80	90	80	80	80	80	80	83	83
90	70	90	70	90	70	80	90	100	80	83	87

3. Inner tree

50	60	40	50	60	60	60	50	50	53	57	50
60	60	40	60	50	50	70	50	60	63	53	50
70	70	60	60	60	60	70	70	60	67	67	60

4. Trunk

	F	NF	F	NF	F	NF	Mean F	Mean NF
5m.	30	20	40	40	40	30	37	30
3m.	40	30	40	30	30	30	37	30
1m.	50	50	40	30	40	30	43	37
.3m.	50	40	30	30	30	20	37	30

F= Trunk facing spray; NF= Trunk not facing spray.

Coverage of trees with droplets using hollow cone nozzles. Application rate = 25 l/tree.

Percentage Coverage with spray.

1. Unpruned side

Tree 1			Tree 2			Tree 3			Mean		
100	60	60	80	80	90	80	100	90	87	80	80
100	100	100	100	90	90	100	100	100	100	97	97
100	100	100	100	100	100	100	100	100	100	100	100

2. Pruned side

100	50	100	90	100	90	100	100	100	97	83	97
100	60	100	90	100	100	100	100	100	97	87	100
100	100	100	100	100	100	100	100	100	100	100	100

3. Inner tree

80	60	60	70	70	60	70	60	50	73	63	57
100	80	70	70	60	60	70	70	60	80	70	63
60	90	100	70	70	80	50	70	80	60	77	87

4. Trunk

							Mean	
	F	NF	F	NF	F	NF	F	NF
5m.	50	50	60	50	70	70	60	57
3m.	70	60	80	70	70	60	73	63
1m.	90	70	80	80	70	60	80	70
.3m.	60	60	50	50	60	50	57	53

F= Trunk facing spray; NF= Trunk not facing spray.

Appendix 3

ATOMISER ADAPTABILITY, COST, DURABILITY AND EASE OF USE

ADAPTABILITY

The Micronair AU8000, Micronex and NORIC slotted rotary drum atomisers were prototype units at the beginning of this study. The AU8000 and X1 are now available as commercial conversion kits for air-assisted sprayers including motorised knapsack mistblowers and axial fan orchard sprayers.

Due to its relatively good droplet size spectra characteristics, the NORIC 7 slotted drum is the drum currently used in Joco tunnel sprayers. It is also being developed for use on fixed wing aircraft.

The restrictors supplied with the atomisers gave flow rate ranges for water of approximately 75 to 1200 ml/min for the AU8000 atomiser and 30 to 180 ml/min for the Micronex when fitted to the Guarany 5 HP knapsack mistblower. Flow regulating restrictors were not supplied with the Noric slotted rotary drum atomisers.

RELATIVE COST

In 1991, the AU8000 was the most expensive atomiser, costing approximately £200.00 compared to approximately £60.00 for the X1 motorised knapsack mistblower and orchard sprayer units. The NORIC atomisers were not available independently of the Joco tunnel sprayers at the time of this study. However, a NORIC atomiser driven by a 24 V motor is likely to be available by 1992 at a cost of approximately £60.00 (de Schaetzen, personal communication). All prices given are the United Kingdom retail prices inclusive of Value Added Tax.

DURABILITY

The AU8000 was made almost entirely from metal, so would be expected to be very robust. Although the plastic X1 was more likely to be damaged in field use, replacement discs were available at relatively low cost.

The mistblower conversion AU8000 unit had a rigid guard to protect the atomiser from operational, transit and storage damage.

The protective cap supplied with the Micronex would protect the disc during transit and storage, but not during operational use when it needs to be removed. It might become misplaced and lost in the field. The Micronex was available from July 1991 with an annular metal guard as an optional fitting to protect the cupped disc.

The Noric slotted rotary drum atomisers were protected by metal guards and deflectors when mounted in tunnel sprayers.

When mounted on axial fan orchard sprayers, the X1 atomisers would require protective guards to deflect branches and prevent damage to the atomiser teeth.

The AU8000 and X1 atomisers are fitted with internal bearings. Raisigl and Felber (1991) encountered problems with the ball races on X1 atomisers fitted to axial fan sprayers for orchard spraying. This problem was not encountered in this study.

Because the Noric slotted rotary drums do not have bearings, they are likely to be less durable than the AU8000 and X1 atomisers.

Early prototypes of the Micronex showed tendencies to liquid leakage at tubing connections but the last unit examined did not have this problem. The Micronex had a pressurised formulation bottle designed so that the output is independent of the height of the nozzle, but as its capacity was only 500 ml, it required frequent refilling. A version is now available with direct liquid delivery from the mistblower formulation tank. Although this allows refilling times to be reduced, flow rates are more dependant upon the atomiser height relative to the formulation tank.

EASE OF USE

All atomisers were easy to use, although the AU8000 was relatively heavy (2.1 kg) compared to the Micronex (1.2 kg). The relatively high weight of the AU8000 would induce greater operator fatigue. To reduce this problem, it is recommended that a lance be used to transfer some of the weight to the mistblower frame.

The X1 atomisers fitted to the axial fan sprayer were easy to use, remove and clean.

Appendix 4

Paper submitted to Crop Protection, July 1991

Evaluation of the X15 stacked spinning disc atomiser of the Ulvamast Mark II vehicle-mounted sprayer.

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ABSTRACT. An improved vehicle-mounted sprayer, the 'Ulvamast Mark II', is described. The droplet size spectra produced by different liquids sprayed through the X15 stacked spinning disc atomiser used on the Ulvamast Mark II were measured using a Malvern laser particle size analyser. An empirical model was developed to predict the Volume Median Diameter (VMD) of the spray within given ranges of atomiser rotation rate, liquid flow rate and liquid physical properties. The model showed general agreement with previous models of rotary disc atomisation.

Introduction

The application of pesticide sprays at ultra-low volume (ULV) rates from vehicles for the control of migrant pests has often involved the use of twin-fluid atomisers (Courshee, 1959; Sayer and Rainey, 1958) and rotary atomisers (Steedman, 1988).

A vehicle-mounted 'Ulvamast'* sprayer utilising a stacked spinning disc atomiser (the 'X15'*) was evaluated for locust control (Symmons et al, 1989) and for armyworm control (Arnold et al, 1989). Although the atomiser and spray rig were found to be robust, safe and easy to operate, the 250 l pesticide tank was considered excessively large, the needle valve was difficult to accurately adjust, the rig was difficult to mount on a Landrover 1.10 vehicle using the J-bolts provided (Arnold et al, 1989) although it could easily be bolted to the floor, and the droplet size spectrum might deteriorate at liquid flow rates below 300 ml/min due to uneven liquid feed to individual discs (Symmons et al, 1989). A new version of the sprayer, the 'Ulvamast Mark II' (Fig. 1) was developed to alleviate these problems.

Description of Ulvamast Mark II sprayer

The Ulvamast Mark II has a 70 l pesticide tank which is a more suitable size for ULV spraying than the 250 l tank on the previous model. Pesticide is pumped from the tank through an adjustable valve to the atomiser. The newly developed centrifugal pump allows the use of certain solvent-based products which were not compatible with the diaphragm pump used with the previous Ulvamast model.

The pump and atomiser are operated remotely from the cab, for ease of use and to reduce operator exposure to pesticide. An auxiliary 10 l flushing tank is provided.

*X15 and Ulvamast are Registered Trade Marks of Micron Sprayers Limited, Bromyard, Herefordshire, UK.

The electrically-driven X15 stacked spinning disc atomiser (Fig. 2) is mounted on a telescopic mast. Each disc has 360 'zero issuing points' (Bals, 1969) or teeth from which liquid leaves the disc as individual direct droplets at very low rates of liquid flow. As flow rate increases, ligaments and finally sheets of liquid leave the teeth; these subsequently break down into droplets of increasing mean diameter with an increase in the range of droplet sizes (Frost, 1981).

The rotation rate of the atomiser is regulated between 3,500 and 9,000 rpm by varying the pulley belt connecting it to the motor. Whereas two 12 V batteries were required to obtain rotation rates above approximately 7000 rpm with the previous X15 atomiser, this can be achieved with a single 12 V vehicle battery with the new model.

The X15 evaluated in this study differed from previous models because the liquid feed system to each disc was improved through changes in disc size and geometry, giving a more even distribution of liquid at low flow rates. The discs were made from black acetal plastic which is more stable to ultra-violet light than the previous white acetal. This helps prevent the brittleness previously observed after prolonged exposure to sunlight when the protective cover was not used (Bals, personal communication).

Evaluation of droplet size spectra produced by X15 atomiser

The droplet size spectra produced by three liquids with different physical properties (Table 1) sprayed through the

X15 atomiser at flow rates between 100 and 3000 ml/min were measured using a Malvern§ ST1800 laser particle size analyser with an 800 mm focal length lens.

Table 1. Liquid physical properties.

Liquid	Density at 20°C(kg/l)	Viscosity at 20°C(cP)	Surface tension (N/m)
Water+0.1 % Agral	1.000	1.05	0.040
Kerosene	0.783	1.78	0.026
Risella	0.875	32.40	0.021

Results and conclusions

The VMD of the spray increased with increasing liquid flow rate (Q), decreasing rotation rate (N), increasing liquid surface tension (σ) and viscosity (μ) (Fig. 3). Rotation rate had a larger effect upon VMD than flow rate. A decrease in

§Malvern Instruments Ltd., Spring Lane South, Malvern, Worcestershire, UK.

rotation rate caused a shift in the volumetric droplet distributions towards the larger size classes (Figs. 4 and 5).

Multiple linear regression data analysis was carried out to develop an empirical model relating VMD to liquid flow rate, atomiser rotation rate and liquid physical properties. Power equations were derived from logarithmic transformations of the independant variables. The following equation was developed for predicting the VMD of the spray produced by the X15 stacked-disc atomiser for liquids with similar physical properties to those evaluated here, at flow rates up to 3000 ml/min and rotation rates of 4000 to 9600 rpm:

$$VMD \approx 196789.Q^{0.18}.N^{-0.60}.\mu^{0.13}.\sigma^{1.10} \quad (r^2=0.96;\ df=303)$$

where Q is liquid flow rate (ml/min), N is rotation rate (rpm), μ is liquid viscosity (cP) and σ is liquid surface tension (N/m). The measured data showed a high degree of correlation to the model (Fig. 6). The model was used to develop contour plots for the prediction of VMD at different flow and rotation rates for water-based pesticides (Fig. 7) and light oil-based formulations (Fig. 8).

The power indices derived in this study are within similar ranges to those produced by most previous studies with spinning disc atomisers (Table 2). The variation in values is due to differences in atomiser design, droplet sizing technique and physical properties of the liquids used for evaluations.

Table 2 Power indices of different empirical rotary atomisation models.

Source	*Q*	*N*	σ	μ
Fraser et al (1957)	0.20	-0.60	0.10	-0.10
Ryley (1959)	0.19	-1.41	-1.35	-1.48
Dombrowski and Lloyd (1974)	0.33	-1.32	-	-0.10
Kayano and Kamiya (1978)	0.32	-0.79	0.26	0.65
Tanasawa et al (1978)	0.10	-1.00	0.50	-
Frost (1981)	0.44	-0.75	0.15	0.02
Kinnersley (1987)	0.16	-0.73	-	-
Present study	0.18	-0.60	1.10	0.13

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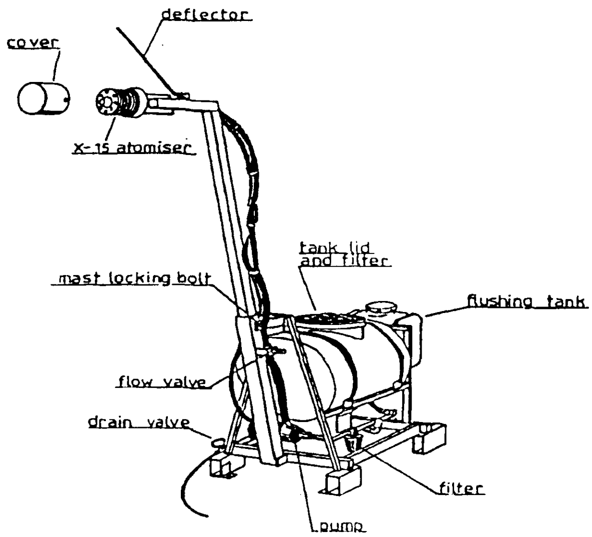
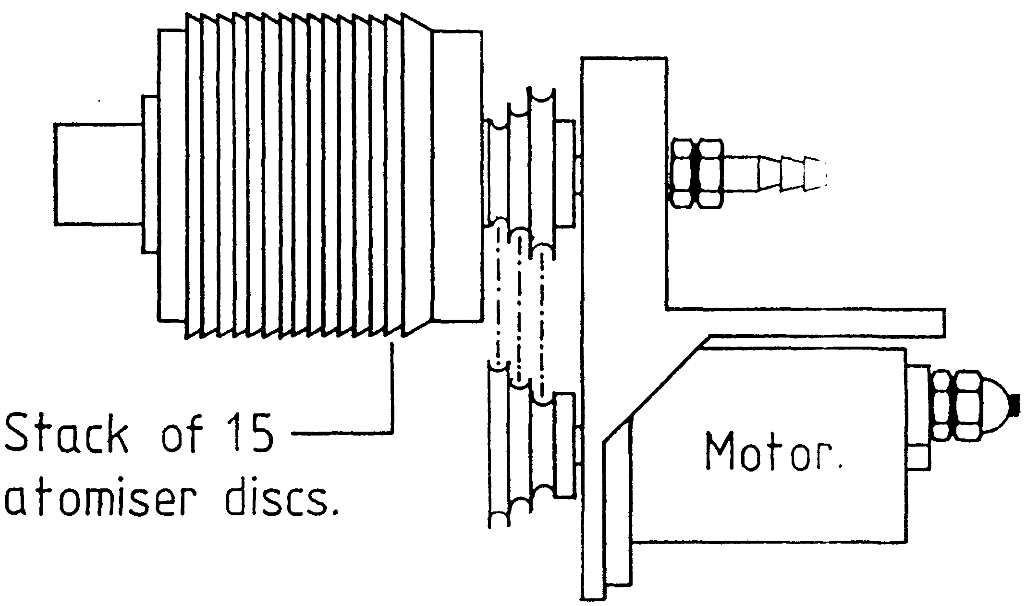
Fig 1. Micron Ulvamast Mark II Sprayer.



(courtsey of Micron Sprayers Ltd.)

Fig 2. X15 Stacked Spinning Disc Rotary Atomiser



(courtesy of Micron Sprayers Ltd.)

Fig.3. VMD against flow rate of different liquids sprayed through X15 atomiser rotating at different rates.

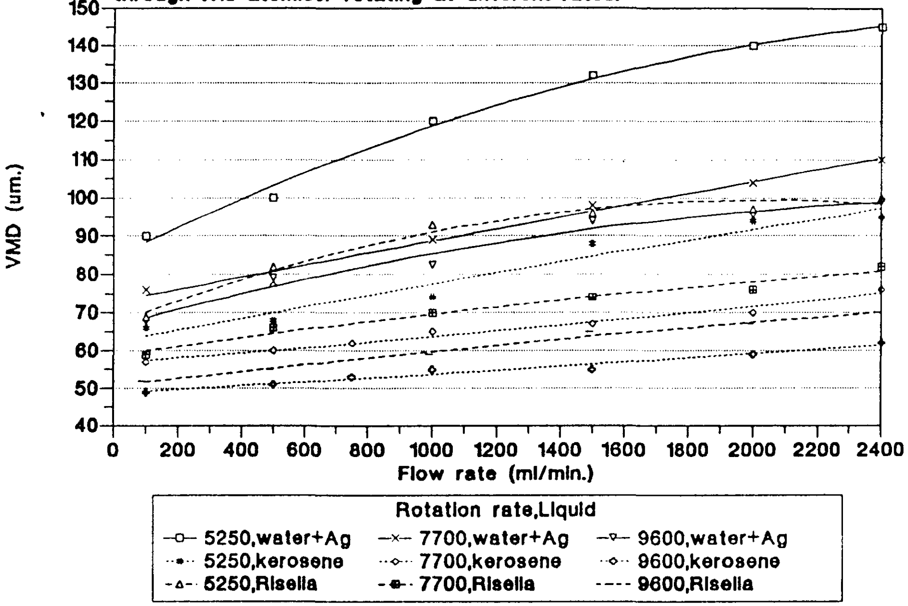


Fig 4. Percentage volume droplet distributions among size classes for kerosene sprayed at different rotation rates through X15 atomiser. Flow rate=500ml/min.

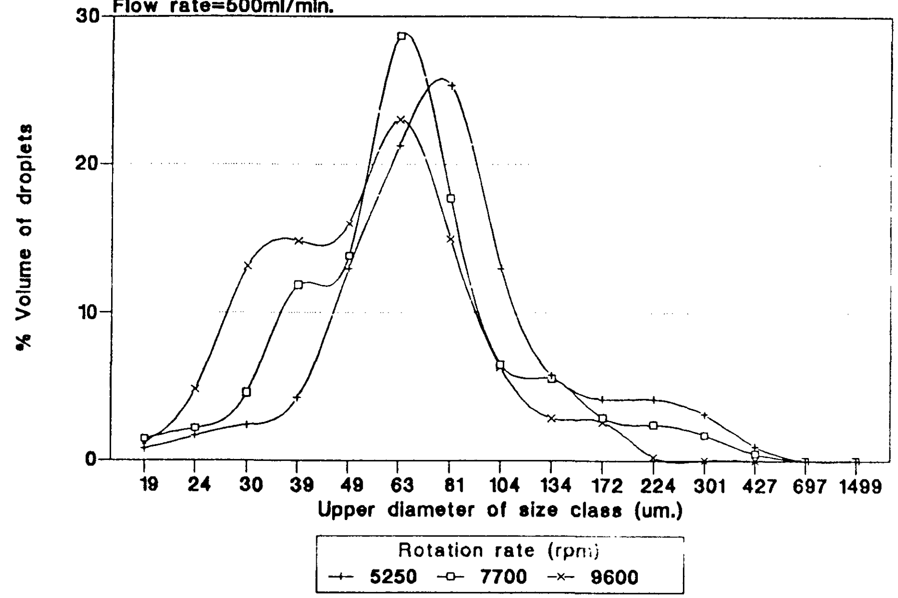


Fig 5. Cumulative percentage volume droplet distributions among size class for kerosene sprayed at different rotation rates through X15 atomiser. Flow rate=500ml/min.

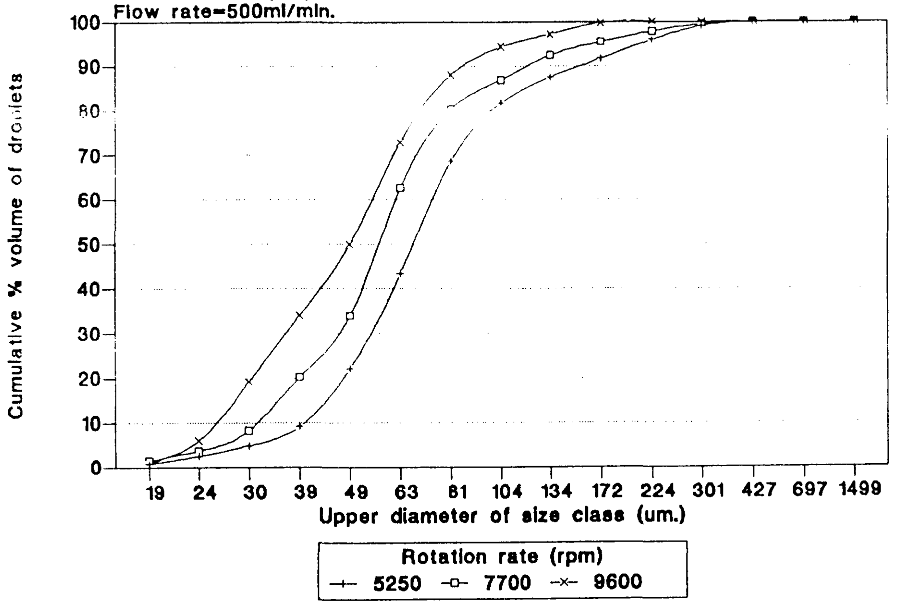


Fig.6. Scatter plot of measured and predicted VMD for X15 atomiser.

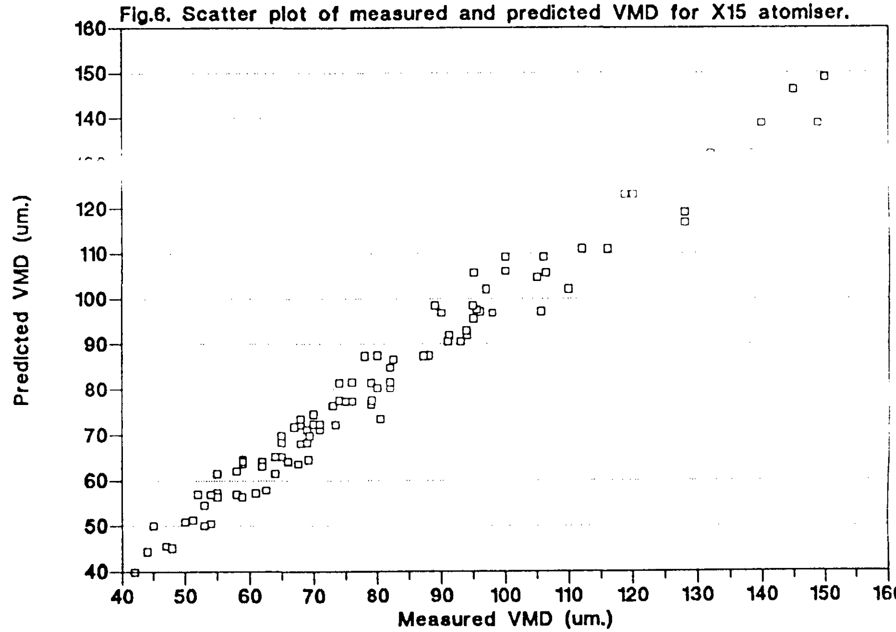


Fig.7. Contour plot for predicting VMD from rotation rate a flow rate of a light oil-based pesticide sprayed through the X15 rota atomiser.

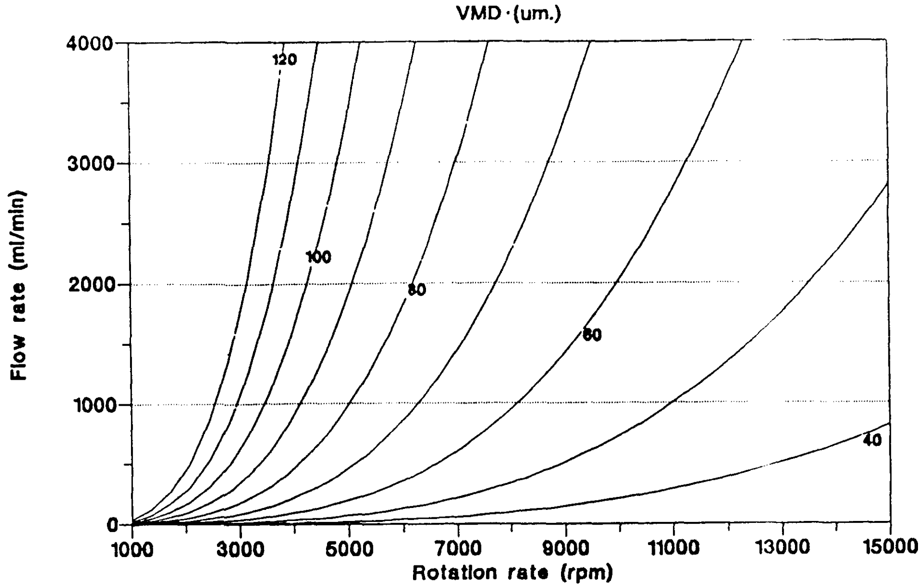


Fig.8. Contour plot for predicting VMD from rotation rate and flow rate of a water-based pesticide sprayed through the X15 rotary atomiser.