INVESTIGATION ON THE EFFECT OF OPERATIONAL AND ATOMIZER PARAMETERS ON THE PERFORMANCE OF BATTERY POWERED SPRAYING SYSTEMS

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CERTIFICATE

This is to certify that the thesis entitled **'Investigation on the effect of operational and atomizer parameters on the performance of battery powered spraying systems'** submitted in part fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Agricultural Engineering (Farm Machinery and Power) to the Tamil Nadu Agricultural University Coimbatore is a record of bona fide research work carried out by Thiru A **Tajuddin**, under my supervision and guidance and that no part of the thesis has been submitted for the award of any other degree diploma, fellowship or other similar titles or prizes and that the work / part of the work has been published in scientific/ popular journal/magazine, reprints of which are appended in the thesis

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AUTHOR

ABSTRACT

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INVESTIGATION ON THE EFFECT OF OPERATIONAL AND ATOMIZER PARAMETERS ON THE PERFORMANCE OF BATTERY POWERED SPRAYING SYSTEMS

By

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Plant protection plays a prominent role in crop production by saving grains from crop insect-pests and diseases By 2000 AD India will need 8 million power sprayers and dusters operated by 1 5 kW engines Annual expenditure on fuel to operate these machines will be around Rs 27,000 million This expenditure can be brought down by using battery powered sprayers in plant protection

The investigation was undertaken with an objective of developing a battery powered sprayer Battery powered hydraulic, pneumatic and centrifugal spraying systems were developed Experiments were conducted to study the effect of operational and atomizer parameters on the performance of the above three spraying systems

A spray patternator was developed to find the spray distribution pattern of the spraying systems. Spread factor was experimentally determined as 0.645 for methylene blue dye - glazed bromide paper combination using a narrow spectrum droplet generator to find the droplet diameter of the spraying systems.

The mean rate of increase in power consumption per unit increase in voltage for the battery powered hydraulic, pneumatic and centrifugal spraying systems were found to be 6.9 W, 3.7 W and 0.63 W respectively.

Minimum coefficient of variation for the spray volume distribution for the three spraying systems were 74.1, 45.6 and 11.7 per cent respectively. Minimum uniformity coefficient of spray droplet size distribution (volume median diameter : numerical median diameter) obtained with the systems were 1.11, 1.23 and 1.03 respectively.

Effective service time per cycle of the battery for the three spraying systems were 30 min, 60 min and 8 h respectively.

Among the three spraying systems, centrifugal spraying system performed better in terms of minimum power consumption, minimum coefficient of variation, more closeness of the uniformity coefficient of dropsize distribution to unity and maximum service time of battery per cycle.

The straight grooved spinning disc could give 11.7 per cent coefficient of variation as compared to 16.4 per cent by inclined grooved spinning disc at the rated capacity of 12 V. The power consumption of straight grooved disc was 9 per cent lesser to that of inclined grooved spinning disc at the rated voltage. The size of droplets produced by straight grooved spinning disc were lesser to inclined grooved disc at all the sampling distances.

A battery powered prototype sprayer was developed adopting the centrifugal spraying system with straight grooved spinning disc at full fluid flow rate of 150 cc min^{-1}.

The battery powered prototype spinning disc sprayer could produce sprays with a volume median diameter of 248 µm at 3580 rev min^{-1} disc speed and uniformity coefficient of 1 01 The sprayer could be operated by battery for a duration of 6 h The sprayer produced 70 dB(A) sound level as compared to 119 dB(A) by power knapsack sprayer

Biological efficacy of the prototype sprayer was 87 6 per cent when compared to 72 6 per cent for the power sprayer Operational cost of the prototype sprayer was Rs 63 ha^{-1} in comparison with Rs 74 ha^{-1} for power sprayer

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CHAPTER I

INTRODUCTION

A grain saved is a grain produced, Plant protection plays a prominent role in crop production since the grains are saved from the crop insect-pests and diseases to feed the ever increasing human population of the world On an average, about one-third of the potential agricultural production of the world is annually lost to the pests In India, crops worth Rs.70,000 million are lost every year Of this, 52 per cent losses are by insects and diseases, 33 per cent by weeds and 15 per cent by rodents, birds and nematodes (Patel, 1988, Sridharan, 1991)

In our country, the plant protection sector dealing with pesticides and equipments has an annual turnover of Rs 15,000 million Plant protection machinery costing around Rs 1000 million are manufactured and sold every year (Nagarajan, 1992) The facts and figures available for avoidable losses justify that plant protection is one of the most important activities for the welfare and survival of mankind

By 2000 AD, India will need 8 million power sprayers and dusters operated by 1 5 kW engines (Nagarajan, 1990) The annual expenditure of our nation in future on fuel to operate these machines would be in the order of Rs 27,000 million at 0 25 litre/kW h specific fuel consumption and 250 h of annual use (IS.9164-1979) Therefore development of battery powered sprayer is essential to overcome the dependence of plant protection equipments on petroleum fuel

At present, spraying chemicals on crops is commonly carried out with power and manual knapsack sprayers Operational cost of power sprayer is more due to escalating cost of petrol Repairs and maintenance costs are also high (Tajuddin and Balasubramanian, 1992) Manual sprayers are high volume sprayers requiring large quantity of water exceeding 400 liters ha^{-1} which puts considerable hardship to the farmers to fetch water especially in arid and semi- arid regions (Attique and Shakeel, 1983) Effective field capacity of these sprayers are usually low (Singh and Chhuneja, 1987) Other drawbacks of high volume sprayers are high labour requirement, non-uniformity of droplet sizes, requirement of higher amount of chemicals and run-off of chemicals on crop canopy (Chaudhury, 1984, Nyirendra, 1988 and 1991, Bayat *et al*, 1994)

Battery powered ultra-low-volume (ULV) sprayers have not become popular in India because of unavailability of ULV pesticide formulations Highly concentrated pesticides are used in ULV sprayers, which pose safety problems to the operator (Morton, 1973) ULV pesticide formulations are expensive and therefore the method of application has to be very efficient (Reed, 1971)

Recent developments in sprayers have indicated that improved droplet formation is possible with less power consumption by using a single spinning disc or cup with grooves on the inner surface (Bals, 1976). The rotary atomizer has the advantage of altering the rotor speed to have predictable drop size with a narrower droplet spectrum (Bals, 1978) Success of rotary atomizer has been due to less wastage and reduced spray volumes (Frost, 1981) Rotary atomizer eliminates droplets smaller than 150 µm, to reduce off-target drift and droplets larger than 300 µm to provide adequate coverage while using low volume application rates The rotary atomizer provides coverage equal to hydraulic nozzles with less drift (Bode *et al.*, 1983).

Rotary atomizers offer the advantages of more efficient utilization of spray chemicals (Ward, 1985) Use of spinning disc atomizer minimises water requirement, reduces spraying cost, saves material and increases labour use efficiency These advantages coupled with the ability to produce sprays with a narrower size spectrum account for their increased popularity (Burt *et al*, 1966, Johnson *et al.*, 1974; Marchant and Dix, 1986) Rotary disc type nozzle is more effective in carrying deposit to nether side of leaves (Zeren and Moser, 1988).

Insecticides applied with hand-carried spinning disc sprayers give similar insect control to that with low volume sprays applied with knapsack sprayers (Johnstone *et al*, 1973) Hand carried spinning disc sprayers have been successfully used to apply several standard wettable powders and emulsifiable concentrate formulations diluted in water for the control of weeds, insect-pests and diseases of many crops (Alcock and Froehlich, 1986; Cowell and Lavers, 1988). The spinning disc sprayers are light in weight, require little water and are convenient to use (Awadhwal and Takenaga, 1989) Spinning disc atomizer can emit reasonably narrower droplet spectrum leading to better capture and use of chemicals and reduced environmental pollution (Hashem, 1991)

When pesticide is applied to crops by a sprayer above the canopy, deposits tend to concentrate on the upper parts of the plants The conventional response to this problem is the use of higher spray volumes, which increases environmental pollution and is not economical for many farmers in developing countries, to whom spinning disc sprayer has provided the greatest benefit (Stonehouse, 1993).

Battery powered sprayer has become the felt need of our farmers, plant protection scientists and Agricultural Engineers as well to overcome many of the problems associated with the application of pesticides But the scientific information available on the performance of different types of battery powered atomizers working on hydraulic, pneumatic and centrifugal principles of atomization, in which case the power is limiting factor, is quite limited Knowledge and scientific evidence confirming the suitability of the type of atomizer for battery powered sprayer would be of immense use for the development of a functionally effective battery powered sprayer

In view of the above, this investigation was undertaken with the following specific objectives

a To develop a spray patternator for studying spray distribution pattern,

b. to determine spread factor for methylene blue dye on glazed bromide paper using a narrow spectrum droplet generator for estimating spray droplet diameter,

c to study the effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics of battery powered spraying systems,

d to develop a prototype sprayer using the parameters optimised in the above investigation and

e to evaluate the performance of the prototype sprayer and to workout the cost-economics based on its performance in the field

CHAPTER II

REVIEW OF LITERATURE

Review of research works relevant to different aspects of the problem under investigation is reported in this chapter. Information on battery powered sprayers are limited except on spinning disc sprayers Therefore development of battery powered sprayer requires investigation on different types of suitable atomizers. Keeping the above in view, the review is presented under the following main headings

a Spray distribution pattern

b Droplet size determination

c Performance of battery powered sprayers

2.1. Spray distribution pattern

Rice (1967) developed a 2440 mm wide spray patternator which was mounted on four flanged wheels running on tracks underneath the spray boom A width of 915 mm in the centre of the patternator was divided into 25 mm bands The spray was collected in glass tubes and the spray pattern was recorded photographically

Thornton and Kibble-White (1974) designed a patternator table of 1550 x 930 mm size rectangular frame which was divided into compartments by means of knife edged strips The sloping channels were made of 1 mm thick galvanized iron (GI) sheet The tube rack consisted of a pivoted frame placed in front of the tube stand below the channels Fifty nine glass tubes were fitted to the rack with bottom ends sealed with plastic caps The tube size was 381 mm long with an internal diameter (ID) of 19 05 mm to have a maximum capacity of 100 cc

Matthews (1979) developed a spray patternator which consisted of metal tray corrugations so that width of each channel was 25 mm The nozzle was mounted 450 mm above the tray He also reported that width of each channel was 50 mm in some patternators

Bureau of Indian Standards (IS 10064-1982) specifies that the spray patternator consists of channels each 25 mm wide and of any convenient length to encompass the spray area The channels lead the liquid directly to the measuring tubes having a maximum bore of 24 mm and a capacity of 200 cc Depth of channels should be atleast 100 mm to avoid rebound of spray droplets into adjacent channels Top edge of the trough dividers should be sharp enough and straight in the horizontal plane so that no point along the edge lies more than 1mm from the straight line

Bode *et al* (1983) evaluated a sprayer in a 3 0 x 1 8 m size spray patternator table having grooves 68 mm apart He analyzed the data from each test to determine the mean liquid flow rate, standard deviation and coefficient of variation (CV) for the spray distribution. Engineers often describe spray pattern uniformity as acceptable when the CV values are less than 15 per cent He found that the liquid flow rates above 1 1 litre min^{-1} did not significantly increase the width of spray pattern

Chaudhury (1984) used a spray patternator of 2600 x 2600 mm size with 40 mm wide stripes to determine the volume distribution across the spray swath

Krishnan *et al* (1988a, 1988b and 1989) developed a technique for measuring spray pattern displacement of agricultural nozzles using an experimental spray patternator operated under dynamic conditions The 4.27 m long and 2 44 m wide patternator was constructed with aluminium angles and 111 right - angled grooves measuring 38 mm peak - to - peak. Spray pattern uniformity was determined quantitatively by calculating the coefficient of variation of the spray pattern. A CV of 10 per cent or less was taken to indicate uniform coverage The CV values between 10 and 15 per cent were considered acceptable coverage

Slocombe *et al* (1990) developed a spray patternator table of 914 x 457 mm corrugated fiberglass with 32 mm corrugations positioned on a 5 per cent slope A 19 mm outside diameter (OD) collection tube was aligned with each valley of the corrugated surface

Dante and Gupta (1991) studied the performance of an electrostatic spinning disc sprayer using a spray patternator. The spray patternator had a surface of 2470 x 1530 mm corrugated GI sheet with 35 mm spacing between grooves

Ozkan *et al*, (1992) performed the spray distribution tests on an automated spray patternator The patternator table consisted of 'V' shaped channels 35 mm wide from peak to peak and 50 mm deep to keep water from splashing into adjacent channels.

Smith (1992) developed a spray patternator, the upper surface of which was of 2.44 x 1.22 m dimensions and was sloped along the 1 22 m dimension Each trough divider was spaced 38 mm apart for a total of 64 troughs The graduated cylinders were mounted on a rack positioned in a vertical plane and rotated away from the table to empty the cylinders at the end of a test The spray volumes were normalised for one minute collection times

Bisen and Devnani (1993) determined spray distribution pattern, swath width and spray angle of different types of hydraulic nozzles on a spray patternator developed as per BIS specifications The spray patternator consisted of spray collection channels of 25 mm width and 100 mm depth made of GI sheet

Awadhwal *et al* (1994) designed and tested a rear mounted mini-boom for knapsack sprayers on a spray patternator. During the tests, the mini-boom was held at a height of 500 mm above the spray patternator table

2.2. Droplet size determination

Studies on different techniques of spray droplet size determination are presented under this section.

2.2.1. Spread factor

Cunnigham (1962) found suitable surfaces for extensive sampling of spray droplets, which included Krome-Kote paper, glazed bromide paper (processed photographic paper) and white glossy paper Spread factor was determined for each surface and dye combination.

Higgins (1967) recommended the use of alternative surfaces for extensive sampling of spray droplets because magnesium deposits were easily damaged in storage

Daum *et al* (1968) conducted experiments with Krome-Kote card and petri-dish containing a thickened water matrix placed side by side in the spray pattern of the droplet generator The card and dish were placed at equal distances from the spinning disc to minimize the range of droplet sizes Droplets collected in the matrix were measured immediately with a biological microscope Krome-Kote cards were placed in slide boxes and stored until the droplet sizes were measured Twenty droplets were measured from each spread factor sample card

Smith *et al*, (1970) determined the spread factor for Guthion dye on Krome-Kote paper using a spinning disc and a narrow spectrum droplet generator. The data for spherical spray droplets captured in the grease matrix and the corresponding data for spread droplets on the Krome-Kote cards were analyzed by curvilinear regression techniques Since the slope of the spherical droplet diameter versus spread droplet diameter appeared to decrease slightly for larger drops, a mathematical model of the form,

$$D = b_0 + b_1 (x) + b_2 (x)^{0.8} + b_3 (x)^{0.5} \quad (2.1)$$

was used in the regression analysis, where D is the spherical diameter and x is the corresponding spread diameter, both in μm

Since the microscope method of measuring spray droplet size was quite time consuming, a maximum of 20 droplets per card were measured. All the spread droplet diameter data were then converted to spherical diameter data using the equation,

$$D = 6.174 + 0.8159 (x)^{0.8} \quad (2.2)$$

which was acceptable since it produced an R^2 value greater than 0.97. This equation was valid where the spherical diameter ranged from 30 to 350 μm

Matthews (1975) collected spray droplets on glass slides coated by burning strips of magnesium ribbon. The slide was in contact with a metal stand to prevent unequal heating of the glass. On impact with magnesium oxide, droplets formed a crater which was 1.15 times larger than the true droplet size. He used a spread factor of 0.86 (reciprocal of 1.15) to convert the measurement of crater to the true size.

Bindra and Singh (1977) reported that Krome-Kote paper, glazed photographic paper and filter paper were used as stain sampling surfaces both for water and oil based sprays. Glossy paper was preferred to filter paper because of non-uniform and irregular spreading of droplets on filter paper. In the case of glossy paper, stains were allowed a few hours to stabilize before measurement Spread factor increased with droplet size Rate of increase in spread factor, however, decreased with increase in droplet size.

Tajuddin *et al* (1982) measured spray droplet size by adding methylene blue 0 75 per cent weight/weight (w/w) with spray liquid and capturing the spray droplets on glossy paper They used the following formula for determining the droplet size

$$D = 0\,318\, S^{1\,065} \qquad (2\,3)$$

where D and S are droplet and stain diameters respectively, μm

Pawar (1988) sampled the drift of spray droplets from a hand-held spinning disc controlled droplet applicator using bromide paper

Regupathy and Dhamu (1990) reported that no spread was necessary for grease matrix as the droplets resumed their original spherical shape The spray liquid could be coloured with a water soluble dye such as methylene blue 0 75 per cent w/w, nigrosine 4 per cent w/w or acid black 4B 1 per cent w/w or oil soluble dye such as croceine scarlet, Rhodomine B, Sudan IV, Waxoline red at 1 per cent w/w according to the spray liquid used

2.2.2 Narrow spectrum droplet generator

Roth and Reins (1957) reported that spray droplets having small diameter could be separated from the primary cloud since they projected a smaller horizontal distance from the spinning disc

Smith *et al.* (1970) developed a narrow spectrum droplet generator with 12 mm semi-circular slot around the periphery of a collection chamber They conducted laboratory tests to determine the trajectory for main cloud droplet diameters of 140, 200 and 300 μm obtained at 6000, 3950 and 2575 rev min^{-1} rotational speeds of 75 mm diameter spinning disc The tests showed that a radius of 285 mm would permit separation of spray satellites from the three desired droplet sizes

Sundaram *et al* (1991) used a commercial spinning disc sprayer capable of producing a narrow range of droplets to generate the smaller size range of droplets A mono-dispersed droplet generator setup was used for this purpose All liquids tested, irrespective of their physical properties, showed an increase in spread factor with increasing droplet size

2.2.3. Droplet size distribution

Fraser (1957) stated that an atomizing device to give controlled and adjustable droplet size within narrow limits is universally required

Hedden (1961) reported that the droplet size generated by a cone nozzle operated at 414 kPa (60 psi) varied from 20 to 580 μm with a VMD of 286 μm

Maksymiuk (1964) reported that the procedure of determining volume median diameter* (VMD) was complicated and time consuming, requiring a series of tedious measurements and computations

* Volume median diameter is defined as the diameter which divides a spray into two equal parts by volume, one half containing droplets smaller than this diameter and the other half containing droplets larger than this diameter

Bals (1969) reported that the efficiency of a sprayer is inversely proportional to the range of droplets it emits, while the suitability of the sprayer for a specific problem depends on the actual size of the droplets emitted

Himel (1969) and Himel and Moore (1969) indicated that the optimum diameter of spray droplets for agricultural applications should be in the range of 200-300 μm

Johnson (1973) considered a coverage of 15 to 20 droplets / cm^2 adequate for controlling most insect pests

Amsden (1975) described the procedure of determining VMD by finding the total volume of spray recorded in each size group, summing up the results and calculating the per cent volume of spray in each size group These figures were then summed cumulatively and the resultant figures plotted against the mean diameters of the corresponding size groups on log-probabilty paper In the absence of such paper, the figures were to be converted to probits before plotting on conventional paper. From this graph, VMD was estimated

Matthews (1975) reported that there were several parameters of droplet size, although the most widely used is VMD In general, a single parameter was inadequate and when assessing the performance of spray nozzles, volume median diameter and numerical median diameter* (NMD) should be quoted together with the method of sampling the droplets

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* Numerical median diameter is defined as the diameter which divides a spray into two equal parts by number, one half containing droplets smaller than this diameter and the other half containing droplets larger than this diameter

Smith *et al.* (1975) experimented with droplets ranging in size from 100 to 300 µm for the control of boll weevil, *Anthomonus grandis grandis* Boheman and reported that the smaller droplets produced the best control

Nawaby (1978) reported that best coating conditions with minimum drift could be obtained with the droplet range of 50 to 400 µm

Matthews (1979) recommended that the most used parameter of droplet size is VMD measured in micrometer, µm The VMD NMD ratio is an indication of the range of droplets in sizes Thus more nearer is the ratio to unity, the more uniform is the size of spray droplets.

Bode *et al* (1983) reported that an indication of the uniformity of droplet spectrum could be obtained from the ratio of VMD to NMD For perfectly uniform droplets, the ratio should be unity

Munthali (1984) reported the increased activity of insecticides with a droplet size range smaller than 100 µm.

Gebhardt *et al* (1985) analyzed the droplet size spectrum data of a rotary cup atomizer and showed that a VMD of 298 µm was more effective in control of weeds than with a VMD of 238 µm.

Ward (1985) evaluated the variation in droplet size by calculating the ratio of VMD to NMD. A value of less than 1.5 for this ratio implied quite uniform size distribution

Culpin (1986) reported that from the drift control view point, there was no worthwhile advantage in a VMD higher than 280 μm

2.3. Performance of battery powered sprayers

Works reported on the performance of hydraulic and pneumatic sprayers are presented Various studies carried out on the development and droplet size distribution of battery powered spinning disc sprayers are also reported under this section

2.3.1 Hydraulic sprayer

Bode *et al* (1968) indicated that the spray patterns from fan spray and cone spray nozzles were more uniform when operated at 275 95 kPa (40 psi) than at 172 47 to 206.96 kPa (25-40 psi) pressure

Bindra and Singh (1977) reported that in the case of hydraulic sprayers, increase in liquid pressure resulted in increased carry of spray droplets, spray angle, liquid flow rate and smaller spray droplets

Patel (1975) reported that hollow cone nozzles gave better coverage of foliage as the droplets approach the leaves from more directions than in the single plane produced by a flat fan nozzle

Smith and Wilkes (1977) found that increasing pressure in hydraulic sprayer decreased the spray droplet size They classified gear pump as positive displacement and self priming pump This pump available in sizes upto 75 7 litre min^{-1} has been used for developing pressure in agricultural sprayers of recent years. They conducted a five year study to determine the effect of nozzle type on the control of cotton insects and found that the hollow cone nozzle gave better insect control and resulted in higher yield of seed cotton than the other types of nozzles.

Bintner *et al* (1977) recommended the use of hollow cone nozzles in crop sprayers to improve the uniformity of spray deposits

Tajuddin *et al* (1978) found that as the speed of plunger pump increased in a tractor mounted hydraulic sprayer, uniformity of spray distribution increased The VMD and NMD of hand operated hydraulic sprayer were 280 0 and 264 8 μm respectively

Matthews (1979) reported that gear pumps were the most commonly used pumps in low and high volume sprayers. Outputs of 5 to 200 litre min^{-1} could be obtained with pressures upto 7 bar, although they were usually operated at lower pressures.

Landers (1991) described a direct injection system sprayer which comprised individual cone bottom pesticide tanks. The tanks were connected to peristaltic tube pumps which metered the pesticides into the induction manifold where it joined with clear water from the spray water tank. The pumps were driven by 12 V variable speed electric motor By varying the motor speed and tube size, the pump could inject pesticide within a wide range of application rates

Mathew *et al* (1992) conducted experiments with a power tiller operated hydraulic sprayer provided with hollow cone nozzles at varying pressure They established the following relationship between pressure and flowrate for the sprayer

$$Y = 270 + 64\ 14\ x \qquad \ldots \quad (2.4)$$

where Y = flow rate, cc min^{-1}

and x = pressure, $kg_f\ cm^{-2}$

They also found that spray angle increased with an increase in pressure as given below

$$S = 52\ 27\ e^{0\ 042X} \qquad (2\ 5)$$

where S = spray angle, deg and x = pressure, $kg_f cm^2$ A decrease in VMD was obtained by increasing the pressure Uniformity of spray was better at 2 and 3 $kg_f\ cm^{-2}$ pressure than that at 4 $kg_f\ cm^{-2}$ pressure

Wang and Schueller (1993) studied on agricultural spraying systems driven by direct-current (DC) motor operated diaphragm pumps Variable motor speeds and pump flow rates were obtained by varying voltage A procedure was developed for finding the flow-pressure-voltage relationship of the diaphragm pumps. Experiments conducted with two diaphragm pumps revealed that the flow rate could be modeled as linearly increasing with voltage and decreasing with pressure

2.3.2. Pneumatic sprayer

Staniland (1960) reported that small air blast machine such as knapsack sprayer gave excellent coverage in row crops

Evans (1968) found that the droplet spectrum produced by a pneumatic sprayer depended on surface tension and viscosity of spray liquid, velocity of liquid emerging from the nozzle and velocity of air flow relative to the spray liquid

Varma and Schroeder (1972) reported that in pneumatic spraying, an air blast of 113 to 226 $m^3\ min^{-1}$ was used for atomization with 2 litre min^{-1} liquid flow rate Spray droplets in this low volume spraying were in the size ranging from 70 to 250 μm with maximum percentage of droplets falling between 100 and 200 μm

Patel (1975) reported that in a power pneumatic sprayer, spray droplet size increased with increase in liquid flow rate and with decrease in air velocity The pneumatic sprayer projected the spray 6 to 8 m horizontally with the air flow rate of 20 to 100 litre s^{-1}

Tajuddin *et al* (1978) found that the critical air flow rate of a power pneumatic sprayer was 6 $m^3\ min^{-1}$ for maximum uniformity of spray distribution and minimum drift. At a given liquid flow rate and engine speed, an increase in the distance from the point of emission had an increasing effect on the mean droplet size upto 51 23 $m\ s^{-1}$ mean air velocity and 6 98 m^3 min^{-1} air flow rate, beyond which the mean droplet size decreased As the liquid flow rate increased, the mean droplet size decreased more or less in a linear manner, however, with a decreasing rate As the blower speed increased, the mean droplet size decreased at an increasing rate. The VMD and NMD of the pneumatic sprayer were 248 0 and 167 60 μm respectively at 4000 rev min^{-1} blower speed and 1125 cc min^{-1} liquid flow rate

2.3.3 Spinning disc sprayer

Bals (1969) quoted the following equation for predicting the spray droplet diameter of spinning disc sprayer

$$d = 3\,8\,\sigma^{0\,5}\,D^{-0\,5}\,\rho^{-0\,5}\,\omega^{-1\,0} \qquad (2\,6)$$

where σ = surface tension of spray liquid, Nm^{-1}

d = droplet diameter, m

D = spinning disc diameter, m

ρ = liquid density, kg m^{-3}

and ω = spinning disc speed, rad s^{-1}

Smith and Burt (1970) considered that 140 μm droplet was the minimum size that could be released from a spinning disc and be deposited dependably in or near the target area

Matthews (1973) reported that the mean droplet size in battery powered spinning disc sprayer would increase with decrease in battery voltage He also found that the mean values of VMD and NMD of spray droplets produced by the spinning disc sprayer at 12 V varied from 56 to 70 μm and from 34 to 42 μm respectively The mean droplet sizes would increase appreciably with increase in the sampling distance from the sprayer

Dombrowski and Lloyd (1974) used the following correlation for the droplet size using liquids whose surface tension and density were effectively constant

$$d = 39\ 33 \times 10^{-5}\ Q^{0\ 334}\ \omega^{-1\ 32}\ D^{-1\ 22}\ \mu^{-0\ 10} \qquad (2\ 7)$$

where d = droplet diameter, m

Q = liquid flow rate, $m^3\ s^{-1}$

D = spinning disc diameter, m and

μ = viscosity, Ns m^{-2}

The above equation revealed that the spray droplet diameter decreased with increasing speed of spinning disc since an increase in the disc speed imparted more energy to the atomizing process

Singh and Bindra (1975) reported that mean droplet size of spinning disc sprayers depended on liquid flow rate, rotational speed of motor or engine, physical properties of spray liquid, environmental conditions and time of application The distance at which the samples were recorded was one of the important factors that influenced the mean droplet size

Boize and Dombrowski (1976) studied Micron rotary atomizer and showed that flow rate and viscosity were non-significant factors They obtained the following correlation that the droplet size was primarily a function of disc speed

$$VMD = 0\ 0107\ n^{-1\ 09} \qquad (2.8)$$

where n is the disc speed in rev s^{-1} In general, droplet size decreased with increasing disc speed and decreasing liquid flow rate

Johnstone and Huntington (1977) defined ULV spray as that in which special ULV formulations are used and VLV spray as that where water based formulations are used

Heinje (1978) studied the spinning cup type atomizer Micron 'Battleship' and showed that VMD decreased with increasing cup speed He also detected a difference in the spray spectrum produced when the liquid flow rate was changed

Kamiya and Kayano (1979) produced the following equations for predicting the mean spray droplet size for a spinning disc sprayer

$$d = 2\ 0\ D(\sigma^{0\ 5}\ \rho^{-0\ 5}\ \omega^{-1\ 0}\ D^{-1\ 5})$$
$$\text{for } \mu < 20 \times 10^{-3}\ \text{Ns m}^{-2} \qquad (2\ 9)$$

and $$d = 2\ 1\ D(\sigma^{0\ 5}\ \rho^{-0\ 5}\ \omega^{-1\ 0}\ D^{-1\ 5})(\mu^{0\ 3}\ Q^{0\ 3}\ \sigma^{-0\ 3}\ D^{-0\ 6})$$
$$\text{for } \mu > 20 \times 10^{-3}\ \text{Ns m}^{-2} \qquad (2\ 10)$$

where d = mean spray droplet diameter, m

σ = surface tension of spray liquid, Nm^{-1}

ρ = liquid density, kg m^{-3}

ω = spinning disc speed, rad s^{-1}

D = spinning disc diameter, m

μ = viscosity of spray liquid, Ns m^{-2}

and Q = liquid flow rate, $m^3\ s^{-1}$

Frost (1981) studied the effect of spinning disc speed, disc diameter, liquid flow rate, density and surface tension on the droplet size distribution of spinning disc sprayers by dimensional analysis He obtained three dimensionless groups viz ,$(\omega\rho D^2\mu^{-1})$, $(\sigma D\rho\mu^{-2})$ and $(Q\rho\mu^{-1}D^{-1})$ Subsequently he developed an expression for the mean droplet size as given below

$$d = 1\ 87\ Q^{0\ 44}\ \sigma^{0\ 15}\ \mu^{0\ 017}\ D^{-0\ 80}\ \omega^{-0\ 75}\ \rho^{-016} \quad .(2\ 11)$$

He concluded in his study that a mean application rate of 50 litres ha^{-1} could be produced with 125 µm mean droplet size using 100 mm diameter spinning disc

Sastry (1981) reported that the diameter of spray droplet was inversely proportional to the speed of spinning disc

Bode *et al* (1983) studied the Micron Micromax cup atomizer and found a decrease in droplet VMD with increasing cup speed They noted significant differences in droplet sizes when the liquid flow rate was changed They found that range in droplet size was relatively narrow at low disc speeds but the range increased significantly at 5000 rev min^{-1} disc speed Spray drift, target deposit and coverage depend largely on the range of droplet size produced by the atomizer

They conducted tests with rotary atomizers to study the spray distribution pattern as a function of flow rate, cup speed, height and spacing between atomizers. Maximum droplet size was obtained at 0 20 litres min^{-1} The droplet size increased as the flow rate increased However the rate of increase reduced as the flow rate increased VMD of 300 µm was obtained at a cup speed of 2000 rev min^{-1} The VMD then increased to 377 µm as the flow rate increased to 3 3 litre min^{-1} At 5000 rev min^{-1} cup speed, VMD increased at a much slower rate as the flow rate increased

They found that the droplet spectrum produced by the Micromax was fairly narrow (VMD NMD <1 3) for flow rates upto 1 0 litre min^{-1} but it became less uniform (VMD NMD >1.6) at higher flow rates This was probably due to the aerodynamic forces causing irregular breakup of liquid ligaments Droplet size was inversely proportional to cup speed. Droplet size decreased very rapidly for increasing cup speeds upto 2000 rev min^{-1} A gradual decrease in droplet size was found for cup speeds above 2000 rev min^{-1}. Effect of cup speed on droplet size was the same at 0.50 as well as at 0.94 litre min^{-1} flow rates The VMD : NMD values were less than 1 6 for cup speeds below 5000 rev min^{-1} However, for cup speed range of 6000 to 7000 rev min^{-1}, the droplet density decreased

Ward (1985) studied the effects of liquid flow rate, viscosity, surface tension, density and spinning disc speed on droplet size distribution through dimensional analysis He derived two dimensionless factors *viz*, ($\sigma^3\ Q\ \omega^{-2}\ \mu^{-3}$) and ($\rho\ \sigma^2\ \omega^{-1}\ \mu^{-3}$) to describe the system performance In the flow rate range of 1 to 5 cc s^{-1} and rotor speed range of 149 to 160 rad s^{-1} direct drop formation occurred when ($\omega Q \rho\ \sigma^{-1}$)< 6 7 and

$$\text{NMD}\ (\mu m) = 3758\ \sigma^{0\ 58}\ \mu^{0\ 18}\ \rho^{-0\ 76}\ \omega^{-0\ 64}\ Q^{-0\ 79} \qquad (R^2 = 0\ 89) \qquad (2\ 12)$$

Derksen and Bode (1986) determined the atomization characteristics of selected rotary atomizers Two replicates of droplet size data revealed that at 2000 rev min^{-1} rotor speed, droplet size decreased as the flow rate increased from 0 10 to 0 15 litre min^{-1} Minimum droplet size occurred at 0 15 litre min^{-1}, then increased as the flow rate increased Increase in flow rate beyond 0 15 litre min^{-1} increased the droplet size Droplet size was inversely proportional to disc speed As the disc speed was increased from 2000 to 5000 rev min^{-1} at 0 15 litre min^{-1} flow rate, VMD decreased from 226 to 121 µm Between 0 15 and 1 00 litre min^{-1} flow rate, VMD did not vary more than 20 µm

Marchant and Dix (1986) derived relationship between dimensionless groups involving torque, motor speed, disc diameter, flow rate, liquid viscosity and density and roughness of the disc for a spinning disc sprayer They found that the torque exerted by the liquid on the disc could be expressed as,

$$T = 0\ 26\ \omega f D^2 \qquad (2\ 13)$$

where T = torque, kg_f m

ω = disc speed, rad s^{-1}

D = disc diameter, m and

f = mass flow rate, kg s^{-1}

Pawar (1986) compared the ultra low volume* controlled droplet applicator (CDA) with the conventional medium high volume** motorized knapsack mist blower and hand-operated knapsack sprayers for insecticide application on pigeon pea A group of three CDA sprayer-heads mounted on a bullock drawn wheeled tool carrier was found to be useful in covering a large area in a short time

Awadhwal and Takenaga (1989) developed a twin spinning disc knapsack sprayer with a 1 5 m wide boom located 300 mm apart from the rear of the liquid container The sprayer equipped with two spinning discs of 50 cc min^{-1} liquid flow rate covered a 3 m wide swath, required 15 litres of water per ha and 1.5 man h ha^{-1} of labour whereas the conventional knapsack sprayer required 400 litres of water per ha and 20 man h ha^{-1} of labour Effective field capacity of the sprayer was 0.66 ha h^{-1} compared to 0 045 ha h^{-1} for the conventional knapsack sprayer.

Symmons *et al* (1989) conducted trials of a ULV formulation of bendiocarb applied with a vehicle mounted spinning disc sprayer The trials revealed that rapid and effective control was consistently achieved at dosages of about 100 g ai+ ha^{-1} The

* ultra low volume < 5 l/ha
** medium high volume 200-600 l/ha (Matthews, 1979).
\+ active ingredients

sprayer proved to be robust, safe, easy to operate and produced a desirable narrow range of small droplets

Tajuddin *et al* (1990 and 1991) developed double and triple spinning disc sprayers. A 10 litre capacity liquid container along with two numbers of 6 V lead-acid rechargeable batteries were fitted to a knapsack frame in the case of double spinning disc sprayer. Two 6 V DC micro-motors alongwith spinning discs were fixed in the front side of a T shaped handle made of 18 x 18 x 3 mm aluminium angle section The triple spinning disc sprayer was made by replacing the T-shaped handle with a 5 m long bamboo pole on which 3 micro-motors with spinning discs were mounted

Tajuddin *et al* (1993) conducted experiments with the double spinning disc sprayer to study the spray distribution pattern when the spinning discs were mounted at 1350, 1500, 1800 and 2100 mm spacings As the spacing between the spinning discs increased from 1350 to 1500 mm, uniformity of spray distribution increased Beyond 1500 mm spacing, uniformity of spray distribution reduced

CHAPTER III

MATERIALS AND METHODS

Development details of spray patternator meant for determining the spray distribution pattern, procedure of determining spread factor for methylene blue on glazed bromide paper for estimating the droplet size of atomized spray fluid, methods of conducting experiments to study the effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics of battery powered hydraulic, pneumatic and centrifugal spraying systems and method of evaluating the performance of the prototype spinning disc sprayer are dealt with in this chapter

3.1. Development of spray patternator

Fabrication details of the spray patternator for studying the spray distribution pattern of various spraying systems are given in this section

3.1.1 Importance of spray patternator

Pesticides worth huge amount of money are wasted annually because improperly calibrated plant protection equipments are used to apply chemicals (Ozkan, 1987) Obtaining correct application rate requires accurately calibrated equipment and an operator who is knowledgable about pesticide application equipment and technology (Rider and Dickey, 1982, Richardson *et al.* 1986) Spray patternator is an important apparatus to study the spray distribution pattern of agricultural sprayers

3.1.2. Fabrication

The spray patternator was developed as per the specifications of Bureau of Indian Standards (IS 10064-1982) The patternator was made by forming 55 numbers of triangular shaped channels, each 30 mm wide at the top and 20 mm deep with 1 mm thick GI sheet Upper and lower dies made of 25x25x6 mm size mild steel (MS) angle sections, Fig 3 1, were used to form channels using a sheet folding machine Total depth of channel was kept as 100 mm by dot welding GI sheet strips of size 1200 x 80 mm on eacn crest of corrugation for the entire length of the channel to avoid rebound of spray droplets

The spray patternator table of 1640 mm length and 1200 mm breadth was mounted on a 20 per cent sloping frame so that the spray fluid can be collected easily The minimum height of the patternator table was kept as 900 mm from ground level so that it is easier to mount the 200 cc capacity measuring glass tubes whose height is 550 mm and also for easier observation A tilting type wooden rack was made to hold 55 numbers of measuring tubes having 25 mm ID A tray of size 1820x300x50 mm made of 1 mm thick GI sheet was used to hold the liquid from the glass tubes after each test, Plate 1

Four numbers of 2 mm diameter MS rods were welded at the top of the vertical GI sheet strip dividers at equal intervals to maintain 30 mm spacing in between each strip throughout the length of dividers A nozzle stand was mounted at the centre of upper edge of the patternator to hold the spray lance Provisions were made to vary

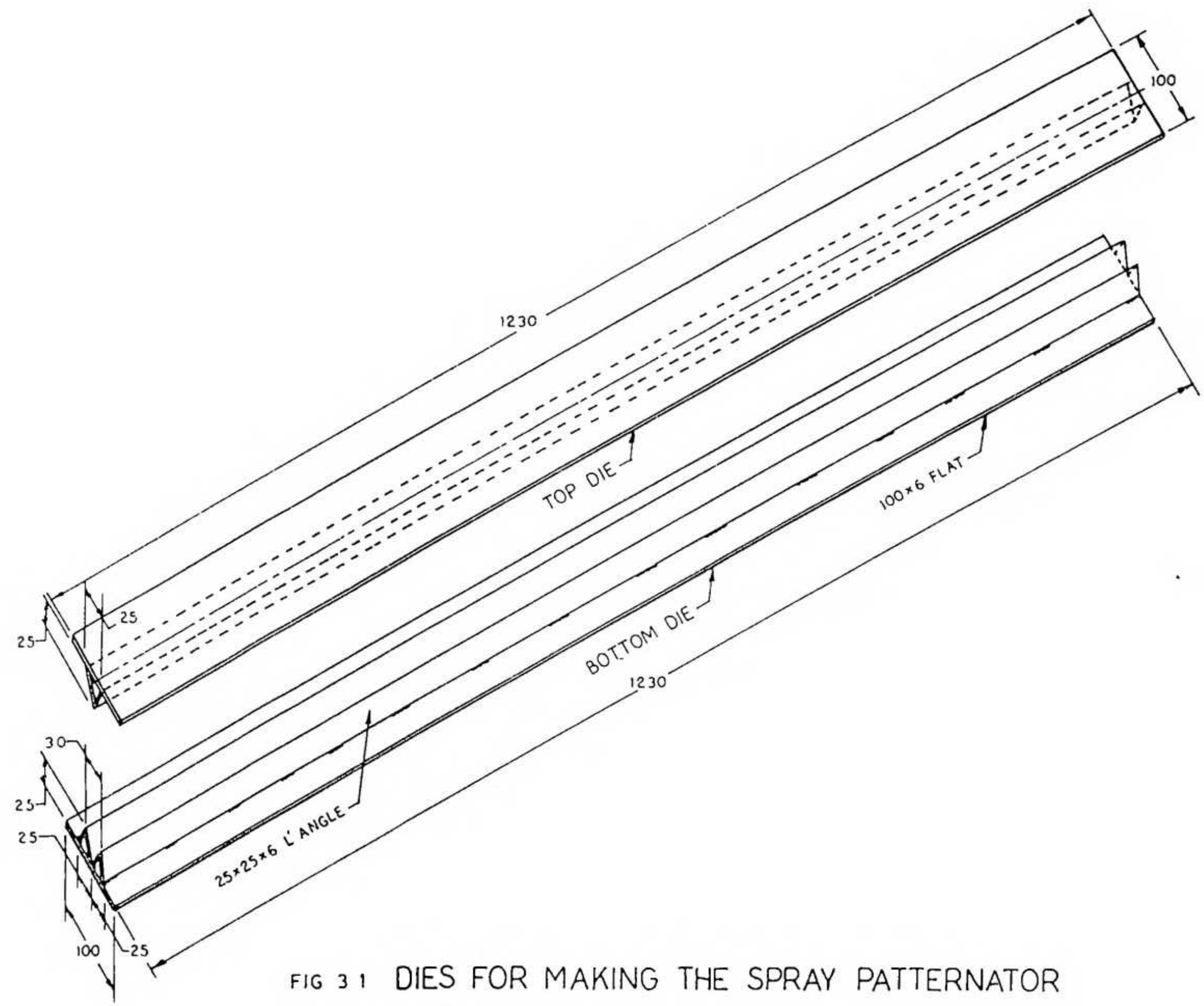


FIG 3 1 DIES FOR MAKING THE SPRAY PATTERNATOR the height of nozzle and angle made by the axis of nozzle with respect to the patternator surface, Fig 3 2 (Tajuddin and Balasubramanian, 1993)

3.1.3. Determination of spray distribution pattern

The spray lance of a rocker sprayer was fitted to the nozzle stand of the spray patternator so that the tip of the hollow cone nozzle (NMD/S 60450) was at a vertical distance of 500 mm from the patternator surface while the axis of the nozzle was at 90° with respect to the patternator surface (Gabrilides, 1964, Awadhwal *et al.,* 1994) One litre of water was taken in the spray tank The sprayer was operated until water ceased to come out of the nozzle The volume of water collected in each of the graduated glass tube was noted The tube rack was then tilted to drain-off the water into the tray and the test was repeated thrice to find the mean value of spray liquid collected in each tube Spray pattern curves were drawn by taking the volume of water along the ordinate and the horizontal distance from the nozzle along the abscissa (Haman and Nordby, 1971, Trefan, 1984, Krishnan, *et al* , 1993) Spray swath width was found from the spray pattern curves Spray angle was determined from the following expression

$$\theta = 2 \tan^{-1} \left\{ \frac{(Sw)}{2H} \right\} \qquad (3\ 1)$$

where θ = spray angle, deg

Sw = spray swath width mm

and H = height of nozzle above the patternator surface, mm

Coefficient of variation (CV) which is widely used to evaluate spray distribution is expressed as the standard deviation of the spray distribution divided by the mean of

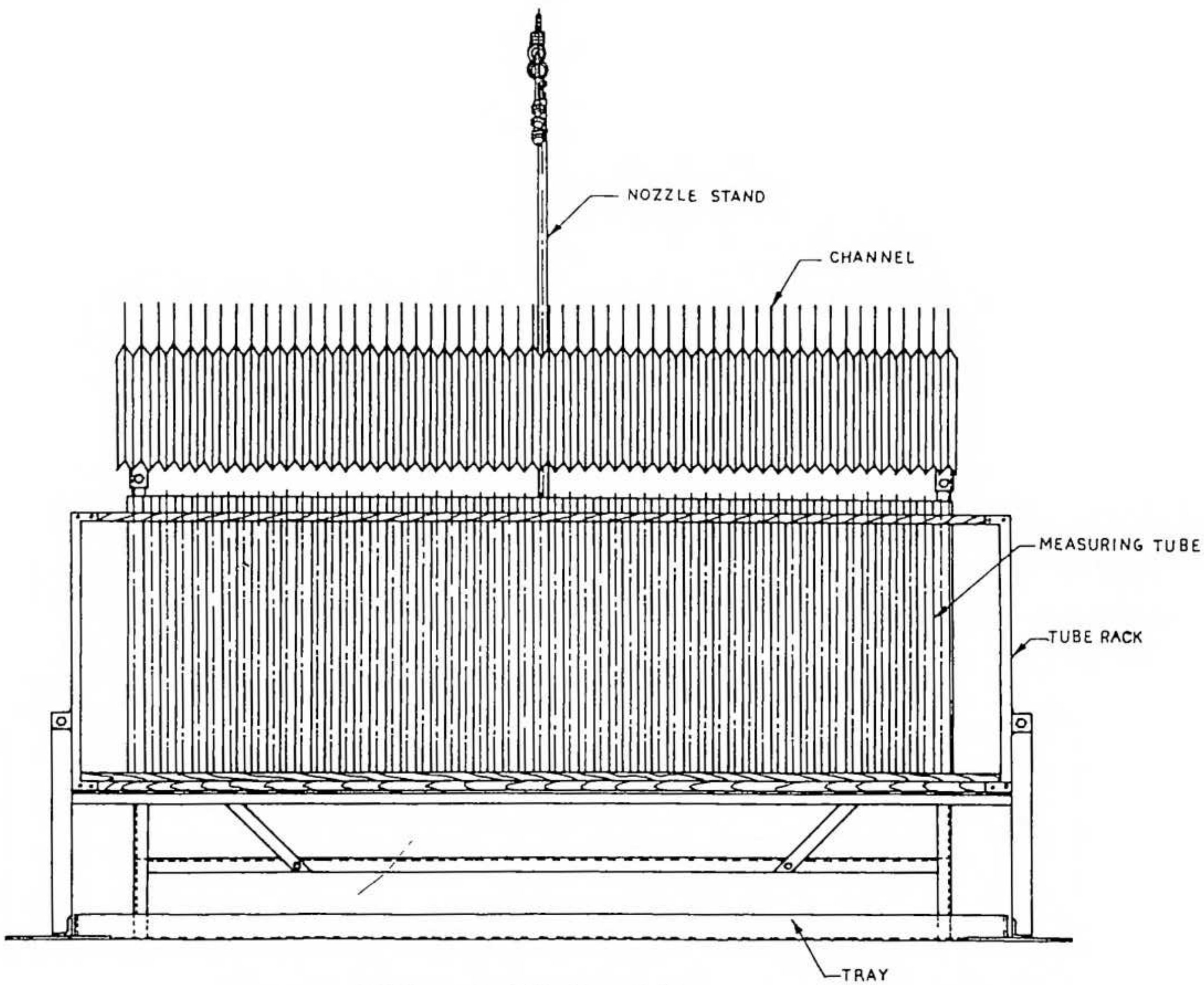


FIG 3.2 SPRAY PATTERNATOR

the distribution (Thierstein *et al.*, 1991; Ozkan and Ackerman, 1992, ASAE Standard, 1993). CV of spray distribution was found by the following formula.

$$CV(\%) = \frac{\sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}}{\bar{x}} \times 100 \qquad (3\ 2)$$

where x_i = amount of spray fluid deposited in the i th channel of the spray patternator, cc

x = mean amount of spray fluid deposited across the spray swath

and n = number of channels into which the spray fluid was deposited

3.2. Determination of spread factor for methylene blue on glazed bromide paper

Spread factor which is the ratio of original spray droplet diameter in space to spread diameter of the droplets on the sampling surface is essential to find the original droplet diameter of spray spectra It is desirable to produce spray droplets of narrower range while finding the spread factor Spray droplets of narrower range were produced by a spinning disc sprayer with low liquid flow rate through a narrow spectrum droplet generator

3.2.1. Development of narrow spectrum droplet generator

A narrow spectrum droplet generator was used to separate smaller and uniform droplets having diameter within the range of 250 to 300 mm from the primary spray cloud (Menzies and Fisher, 1975, Panneton *et al*, 1991) The narrow spectrum droplet generator was made of 1 mm GI sheet to form a drum of 600 mm diameter and 100 mm depth A 12 mm wide rectangular slot was made for half the circumferencial length of the drum (Smith *et al*, 1970) A drain pipe was provided at the bottom of the drum to drain-off the liquid entrapped in the drum A 150x100 mm size opening was provided at the top of the drum, through which the spinning disc along with the micro-motor was protruded, Plate 2

3.2.2. Selection of stain and sampling surface

The following water soluble stains were used on glossy art paper and glazed bromide paper

a) Nigrosine 4 per cent w/w

b) Acid black 4B 1 percent w/w

c) Methylene blue 0 75 percent w/w (Regupathy and Dhamu, 1990)

Methylene blue (powder) was selected for easy availability and lesser requirement of the dye material When viewed under microscope, stains on glossy paper were observed to have irregular edges (Jarman, 1956, Rose, 1963) and the stains on glazed bromide paper were round with well defined edges (Johnstone, 1960) Hence the glazed bromide paper was selected as the sampling surface to capture the methylene blue dyed spray droplets, Plate 3

3.2.3. Calibration of ocular micrometer

One division of ocular micrometer in the biological microscope with a multiplication of 10 was calibrated in terms of stage micrometer divisions by observing the coincidence of divisions in ocular and stage micrometers One mm is divided into 100 equal divisions in the stage micrometer One ocular micrometer division was calibrated in terms of μm The stained bromide papers were kept under the

Plate 1. Spray patternator

Plate 2. Spread factor determination with narrow spectrum droplet generator

microscope and the outer diameter of stains were measured in terms of ocular divisions and then converted into µm

3.2 4. Determination of spread factor

Methylene blue (powder) was added to water at the rate of 0 75 per cent w/w (Bode *et al* 1968, Singh and Bindra, 1975, Matthews, 1979) Uniform sized droplets were produced using a spinning disc operated by a 0-30 V, 0-5 A capacity regulated DC power supply with low (57 cc min^{-1}) flow rate (Courshee, 1960, Matthews, 1992) The dyed water was filled in the liquid container of the spinning disc sprayer

Grease matrix was prepared in petri-dishes by mixing liquid paraffin and petroleum jelly (vaseline) @ 2 1 w/w (Cunnigham, *et al*, 1962, Matthews, 1979, Babu *et al*, 1990) The matrix was gently heated until a homogeneous mixture was formed Bromide paper was cut into square pieces of 80 mm side, which is equivalent to the area of a petri-dish

The spinning disc along with the micro-motor was placed such that the spinning disc was within the narrow spectrum droplet generator The spinning disc was operated at 5 voltage levels ranging from 4 to 6 V at intervals of 0 5 V of the regulated power supply which converts 220 V AC to DC Petri-dish and bromide paper were placed side by side at 200 mm horizontal distance and 200 mm vertical distance from the peripheral opening of the narrow spectrum droplet generator, Plate 2 At each voltage, the droplets were captured on the petri-dish and bromide paper for 10 s

Droplets captured in petri-dishes were immediately covered by a thin layer of liquid paraffin to avoid evaporation losses (Haman and Nordby, 1971), Plate 4, and the diameters of droplets in the grease matrix were then measured in the microscope Stained bromide papers were stored for 24 h for complete spreading of stains and then the spread diameters of stains were measured in the microscope The experiment was repeated thrice Fifty droplets were measured in each sample petri-dish and bromide paper Correlation between mean spherical diameters and mean stain diameters of droplets was drawn

3.3 Effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics

Three types of battery powered spraying systems working on the principles of hydraulic, pneumatic and centrifugal atomization were developed Experiments were conducted to investigate the effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics of the above three spraying systems

3.3.1. Hydraulic spraying system

The hydraulic spraying system is operated by a 12 V, 17 W DC motor which drives a gear pump to develop the hydraulic pressure, Plate 5 Inlet of the gear pump was connected to a 10 litre capacity liquid container by a 6 mm ID plastic hose Outlet of the gear pump was connected to a spray lance through a bourden pressure gauge of 490 kPa (5 kg_f/cm^2) capacity, Fig 3 3 The sprayer was tested with hollow cone nozzle

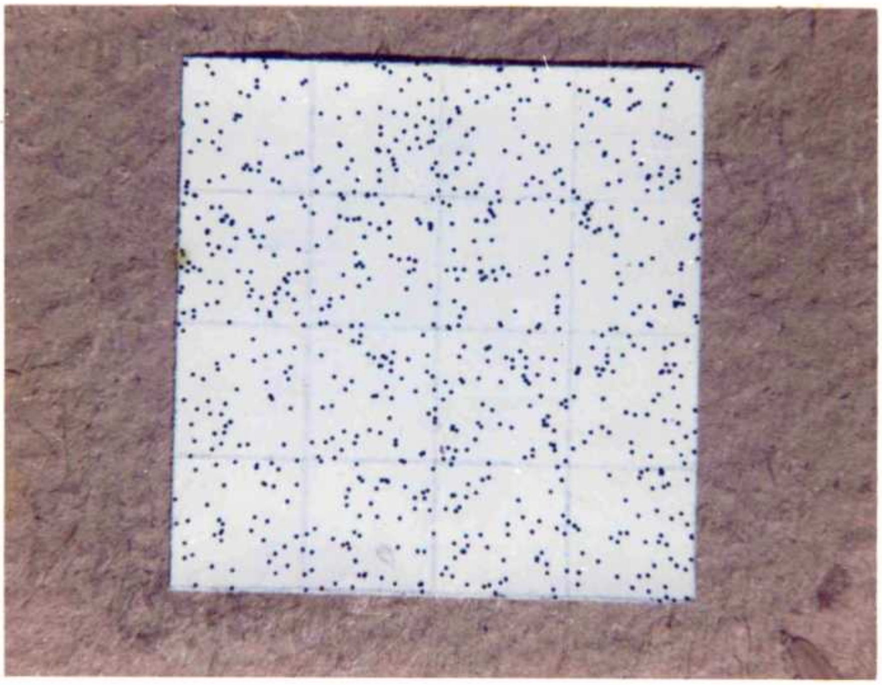


Plate 3. Glazed bromide paper with stains of methylene blue dyed spray droplets

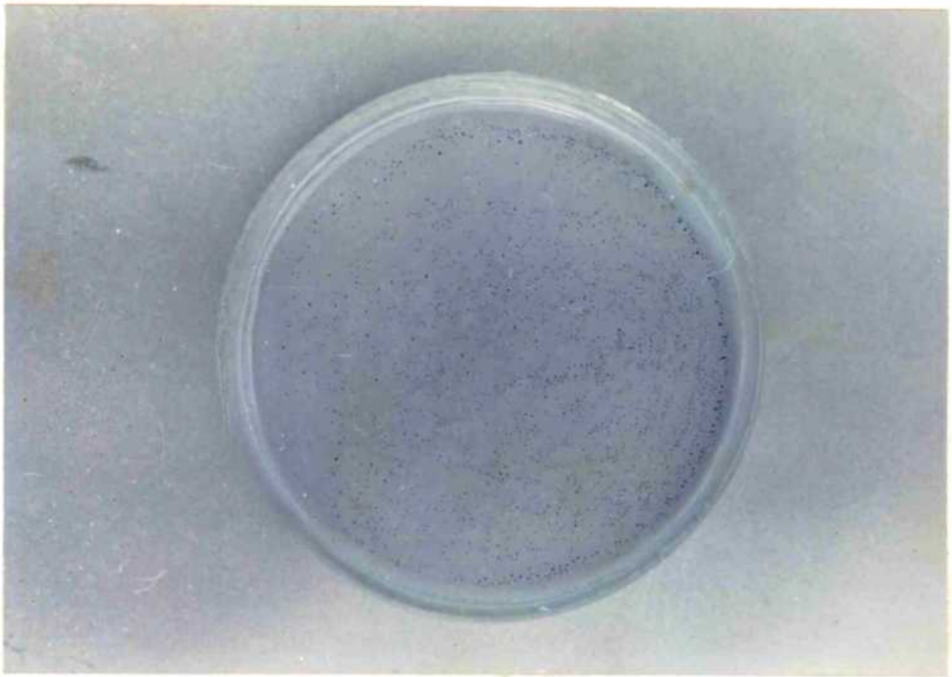


Plate 4. Spray droplets captured in grease matrix in petridish

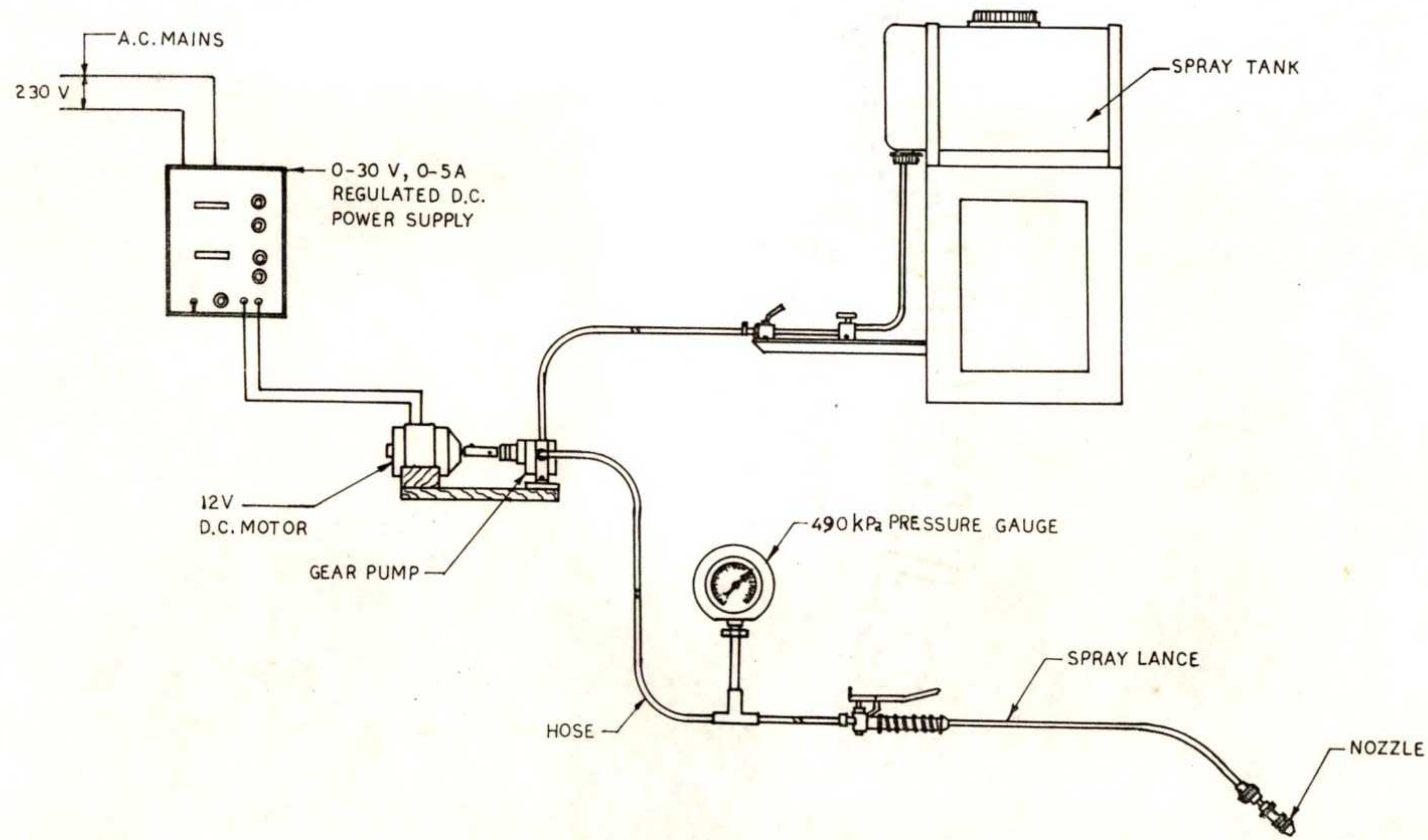


FIG. 3.3 EXPERIMENTAL HYDRAULIC SPRAYER WITH GEAR PUMP DRIVEN BY 12 V DC MOTOR

which is mostly used for spraying insecticides (Azeez Basha, 1994) and with a flat fan nozzle which is commonly used for spraying herbicides

a. Components of power consumption

Normally a battery is used upto 80 percent level of the rated voltage Since the battery used in the present study is of 12 V, it can be used upto 9 6 V However to have a clearcut understanding of the components of power consumption for self-running of the motor, operating the gear pump and pumping the fluid at different voltage levels, the DC motor was operated in the voltage range of 6 to 12 V at 1 V interval The voltage was varied by the regulated DC power supply having digital displays for voltage and amperage measurements

The DC motor without gear pump was operated in the above voltage range and interval Amperage readings of the DC power supply were noted to find the power consumption (voltage x amperage) of the motor Rotational speed of the motor was measured using the non-contact digital tachometer at each voltage level Ten tachometer readings were taken in each test to compute the mean The test was replicated thrice The above experiment was repeated after coupling the gear pump with the motor under the condition of no load and then under load

b. Effect of liquid pressure on spray performance

An experiment was conducted with the DC motor operated hydraulic spraying system to study the effect of varying voltage on liquid pressure Methods of conducting experiments to study the effect of liquid pressure on spray distribution pattern, spray characteristics *viz.*, liquid flow rate, spray width and spray angle and on atomization characteristics of the spraying system with hollow cone nozzle and flat fan nozzle are given below

i. Spray distribution pattern

The experiment was conducted at 5 levels of voltage to have 5 corresponding levels of liquid pressure varying from 44 to 113 kPa The voltage was varied from 8 to 12 V at an increment of 1V by the regulated DC power supply The spray lance fitted with the hollow cone nozzle (NMD/S 60450) was mounted on the nozzle stand of the spray patternator at a height of 500 mm from the patternator surface and the axis of the nozzle was normal to the patternator surface The inlet and outlet of the gear pump were connected to the liquid container and spray lance respectively The motor was operated for 2 min duration in each test with full tank volume of water to avoid variation in pressure head

Spray volume collected in each of the measuring glass tube of the spray patternator was noted, Plate 6 The test was replicated thrice The spray distribution pattern curves were drawn using the mean values Coefficient of variation was computed using the equation 3 2 The experiment was repeated for the flat fan nozzle (XLT 60675) following the above procedure

ii. Spray characteristics

For each test in the above experiment, liquid pressure reading in the pressure gauge was noted, liquid flow rate was determined by measuring the time taken for

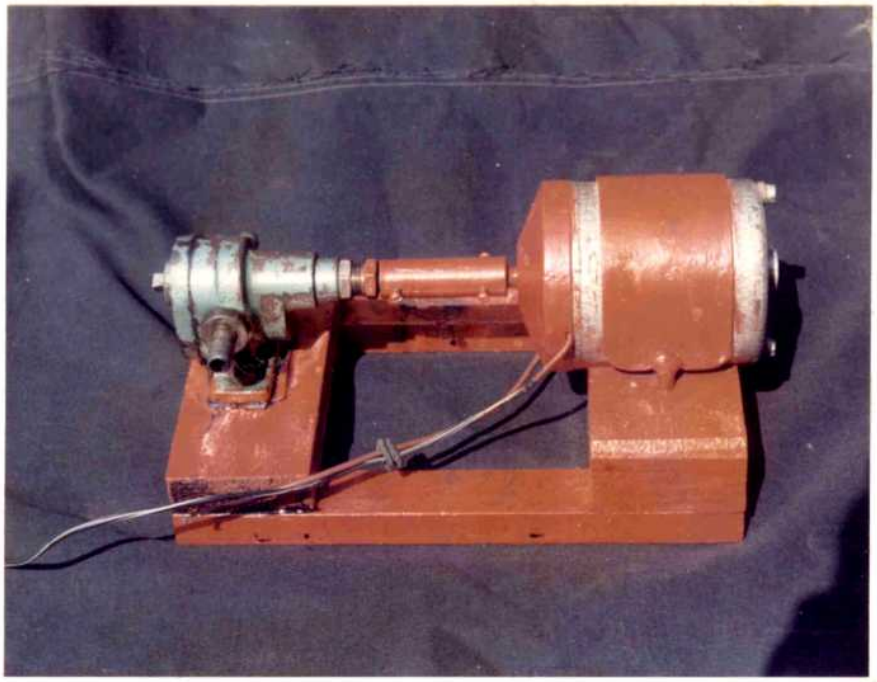


Plate 5. Gear pump coupled with 12V DC motor

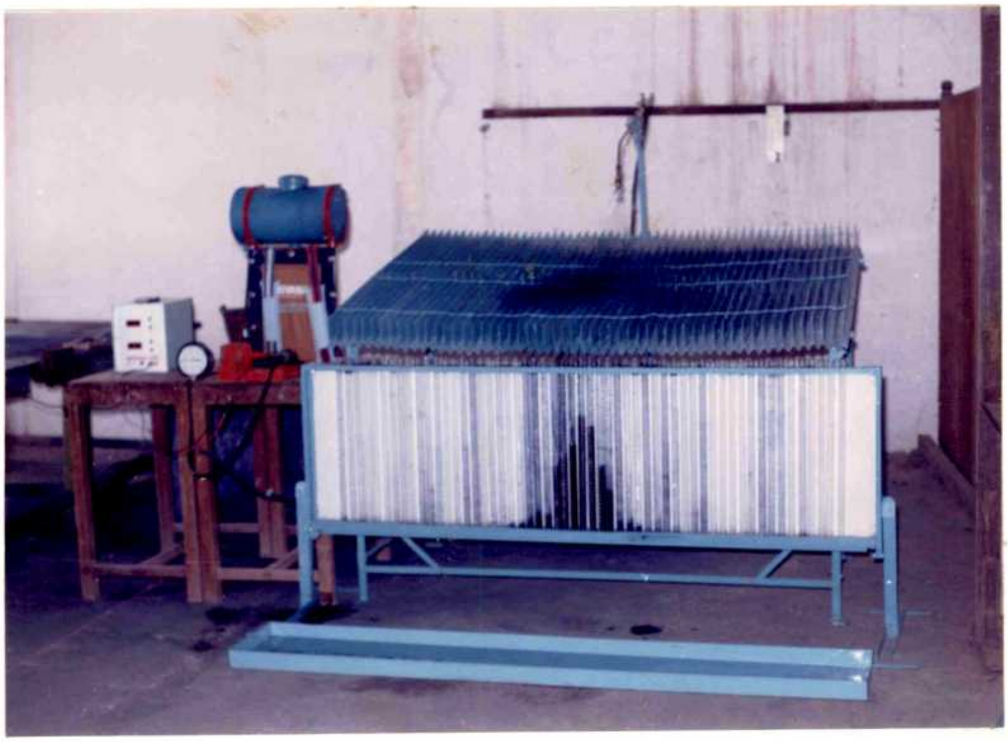


Plate 6. Spray distribution pattern of DC motor operated hydraulic spraying system

collecting 1 litre of water from the nozzle, spray swath width was found from the spray pattern curve and spray angle was determined as per the equation 3 1

iii. Atomization characteristics

Methylene blue dye 0 75 per cent w/w was added to water For each test during the above experiment, the spray droplets were captured on the glazed bromide papers of 40 x 40 mm size at a horizontal distance of 150 mm from the nozzle for 10 s duration Three replications were made After allowing 24 h for complete spreading of stains on the bromide papers, stain diameters were measured in the biological microscope Droplet diameters were found from the above values using the mean spread factor of 0 645, as determined in section 3 2 4

Empirical probit values for the cumulative percentages of frequency of droplets and for the cumulative percentages of volume of droplets were found from the tables The probit values were plotted against the log mean diameter of droplets Anti-log of the abscissa for the probit value of 5 gives the values of NMD and VMD respectively (Regupathy and Dhamu, 1990) A computer program exclusively developed for this purpose was used to compute the values of NMD and VMD for each test card Fifty stain diameters were measured in each test card

c. Energy release pattern of battery

An experiment was conducted to study the energy release pattern of the battery with respect to the operating time when the spraying system was operated continuously with a battery The spraying system was operated with a fully charged 12 V 5 A h lead acid battery continuously until the DC motor ceased to rotate After every 10 min of operation, battery voltage, motor speed, liquid pressure and liquid flow rate were measured Battery voltage was measured using a AC-DC multimeter Three replications were made

3.3.2. Pneumatic spraying system

A 24 V, 25 W DC motor coupled with centrifugal blower was used to create the air blast to break the droplets An air outlet pipe was made of 1 mm thick GI sheet, 475 mm long, 35 mm OD at the inlet end and 10 mm OD at the outlet end A 25 mm long nipple with 1 mm bore was made of gun metal and fixed at the outlet end of the air outlet pipe, Fig 3 4 The nipple was connected to a 10 litre capacity liquid container by a 6 mm ID plastic hose through a flow control valve, Plate 7

a. Components of power consumption

The DC motor blower was operated at the voltage range of 12 to 24 V at an increment of 1 V by the regulated DC power supply At each voltage level, rotational speed of the blower was measured by the contactless digital tachometer, amperage reading in the power supply was taken to find the power consumption and the air velocity at the outlet end was measured using a digital vane type wind anemometer The test was replicated thrice under the condition of no load and the mean values were found The experiment was repeated under load

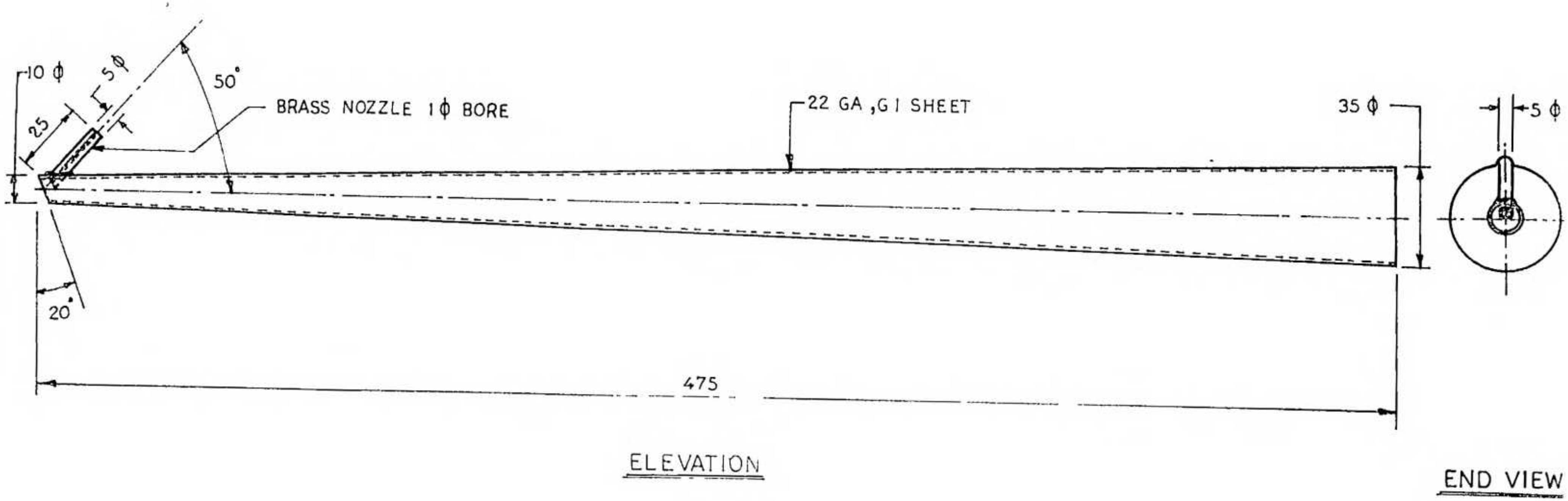


FIG. 3.4. AIR OUTLET PIPE OF PNEUMATIC SPRAYING SYSTEM

b. Effect of air velocity on spray performance

An expenment was conducted with the DC motor operated pneumatic spraying system to study the effect of varying voltage on blower air velocity Method of conducting expenments to study the effect of air velocity on spray distribution pattern and atomization charactenstics of the spraying system at different liquid flow rates are given below

i. Spray distribution pattern

The expenment was conducted at 5 levels of voltage to have 5 corresponding levels of air velocity varying from 4 1 to 5 6 ms^{-1} and 3 levels of liquid flow rates *viz*, 50, 65 and 80 cc min^{-1} The voltage was vaned from 16 to 24 V at an increment of 2 V by the regulated DC power supply Liquid flow rate was varied by the flow control valve Three replications were made

The outlet end of the air outlet pipe was placed at the centre of one edge of the spray patternator at a vertical distance of 500 mm above the patternator surface The system was operated for 15 min duration in each test. Volume of water collected in each measunng glass tube of the spray patternator was noted after each test The liquid container was filled up to the full level to maintain the same pressure head for all the tests Using the mean values, spray distnbution pattern curves were drawn and coefficient of variation was computed for each test From the spray pattern curves, the length of spray was found for each test

ii. Atomization characteristics

Glazed bromide papers of 40x40 mm size were placed 200 mm apart in 3 rows, one along the axis, one 200 mm to the left and the other 200 mm to the right of the nozzle Methylene blue was added to water at 0 75 per cent w/w In each test of the experiment as mentioned in the above section, spray droplets were captured on the bromide papers for 3 s duration The sample cards were stored and 50 stain diameters were measured under microscope in each test card VMD and NMD of each spray test card were determined using the computer program

c. Energy release pattern of battery

The system was operated with two numbers of fully charged 12 V, 5 A h lead-acid batteries connected in series continuously until an apparent reduction in blower speed was observed At every 10 min interval, voltage of batteries, motor amperage, blower speed and air velocity measurements were made The test was replicated thrice

3.3.3. Centrifugal spraying system

The system consists a spinning disc operated by a 12 V DC motor fixed at the end of an aluminum handle, Plate 8. Spray liquid was taken from a 10 litre capacity liquid container to the spinning disc through a flow control valve. Two identical spinning discs with 94 mm diameter OD and 3 mm thick were made of aluminium, Fig35 Provisions were made at the centre of the spinning discs to fix the discs to the motor shaft Grooves were made at 1mm pitch in the inclined surface at the inner side of the

Plate 7. DC motor operated pneumatic spraying system

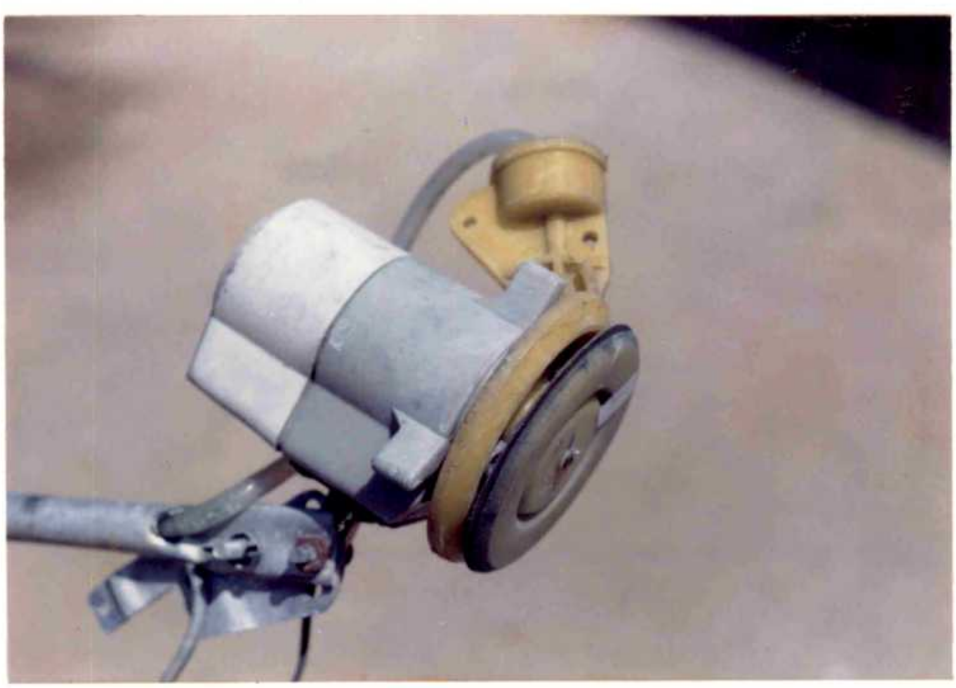
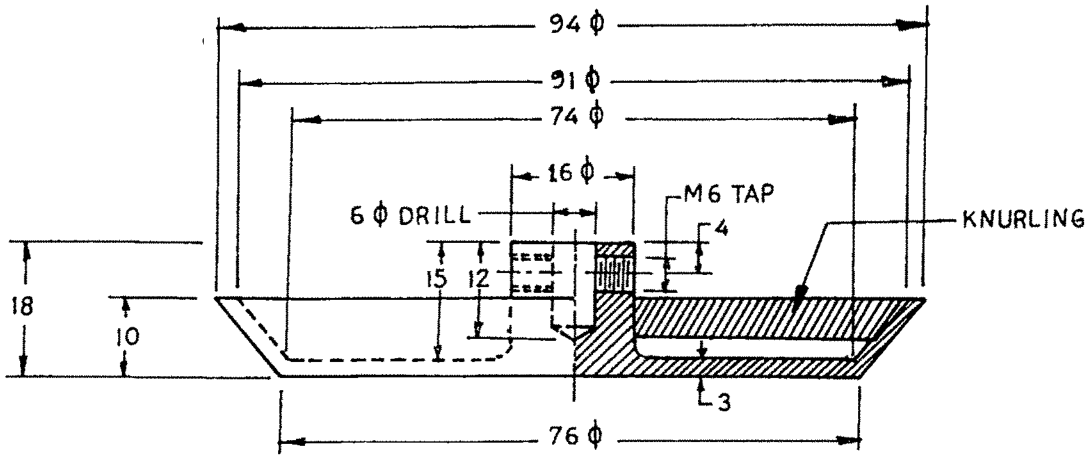
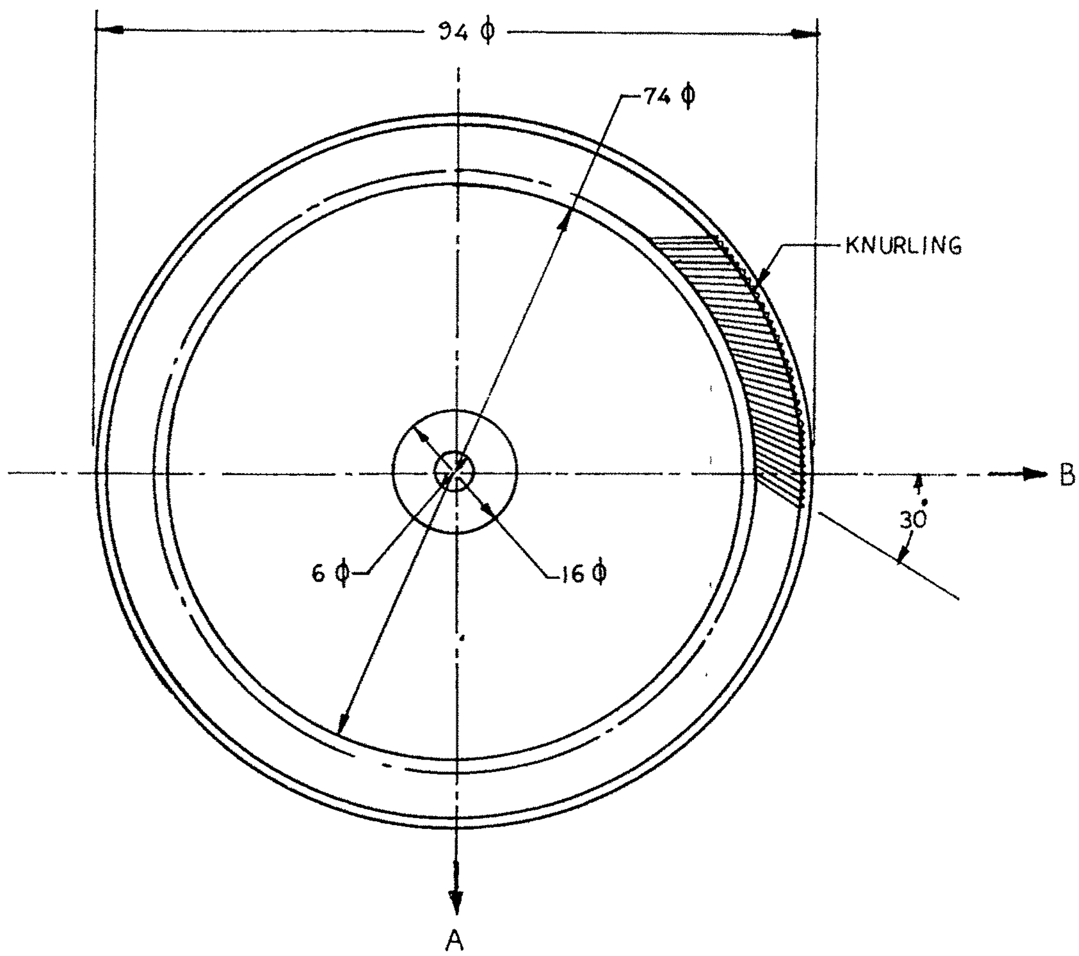


Plate 8. DC motor operated spinning disc



SECTIONAL ELEVATION ON 'AB'



PLAN

FIG.3.5 SPINNING DISC WITH INCLINED GROOVES spinning discs using knurling tool in lathe In one spinning disc straight grooves were made and in another disc 30° inclined grooves were made

a. Effect of design and speed of spinning disc on spray performance

Methods of conducting experiments to study the effect of design and speed of spinning disc on spray distribution pattern and atomization characteristics of the spraying system at different flow rates are given below

i. Spray distribution pattern

The experiment was conducted at 5 levels of voltage *viz*, 8,9,10,11 and 12 V to have 5 corresponding levels of spinning disc speed varying from 2000 to 4200 rev min^{-1}, two levels of liquid flow rates *viz*, 75 and 150 cc min^{-1} and two types of spinning discs *viz*, inclined grooved and straight grooved spinning discs Three replications were made

The aluminium handle along with the DC motor and spinning disc was fitted to the nozzle stand of the spray patternator so that the spinning disc was at a height of 500 mm from the patternator table and the axis of the spinning disc was normal to the patternator surface. Each test was carried out with full tank volume of water The system was operated for 15 min duration in each test Volume of water collected in each measuring glass tube of the spray patternator was noted after each test Spray distribution pattern curves were drawn and the coefficient of variation was found from the mean values From the spray pattern curves, the length of spray was found for each test

ii. Atomization characteristics

Glazed bromide papers of 40 x 40 mm size were placed on the flat floor 500 mm vertically downwards (Morton, 1973) and 600,800 and 1000 mm horizontally forwards from the spinning disc centre Methylene blue was added to water at 0 75 per cent w/w and the spray droplets were captured on the bromide papers for 10 s duration in each test of the experiment described in the above section The stained bromide cards were stored and 50 stain diameters were measured under microscope in each test card VMD and NMD of each test card were determined using the computer program

c. Energy release pattern of battery

An experiment was conducted to study the effect of operating the system continuously with battery on battery voltage, motor amperage and spinning disc speed The system was operated at the full liquid flow rate of 150 cc min^{-1} with a fully charged 12 V, 5A h lead-acid battery continuously until the spinning disc speed was notably reduced At every one hour of operation, battery voltage and motor amperage were measured using AC-DC multimeter and rotational speed of the spinning disc was measured using the contactless digital tachometer The test was replicated thrice and the mean values were found.

3.4. Development of battery powered prototype spinning disc sprayer

Among the hydraulic, pneumatic and centrifugal spraying systems, the best system for operating with battery was selected and the operational and atomizer parameters were optimised from the experimental results of this investigation Using the optimised parameters, a battery powered prototype spinning disc sprayer was developed

3.4.1. Selection of spraying system

The battery powered hydraulic, pneumatic and centrifugal spraying systems were compared in terms of power consumption, CV, VMD/NMD ratio and battery operative time per cycle Among the above three systems, centrifugal spraying system had minimum power consumption, CV and VMD/NMD ratio and maximum battery operative time per cycle Therefore the centrifugal spraying system was selected

3.4.2. Development details

Development details of components of the prototype spinning disc sprayer are given below

a. Liquid tank

Minimum CV was obtained with the full fluid flow rate of 150 cc min^{-1} By assuming that the liquid tank is filled once in an hour, the volume required is 9 00 litres Besides an average operator can carry a load of 10 kg continuously on his back without much fatigue Therefore a 10 litre capacity plastic tank was used as the liquid tank of the prototype sprayer

b. Handle

The handle was made of 18 mm OD and 1 2 m long aluminum pipe to minimise the ill-effects of pesticide contamination on the operator The switch was fixed to the handle adjacent to the handle grip

c. DC motor

The 12 V DC motor used for the centrifugal spraying system weighs 0 5 kg It produces a maximum bending moment of 0 60 kg m at the free end of the handle and hence it is difficult to hold the handle with 12 V motor continuously Therefore, a light weight 6 V DC motor having similar operating characteristics was used in the prototype sprayer

d. Spinning disc

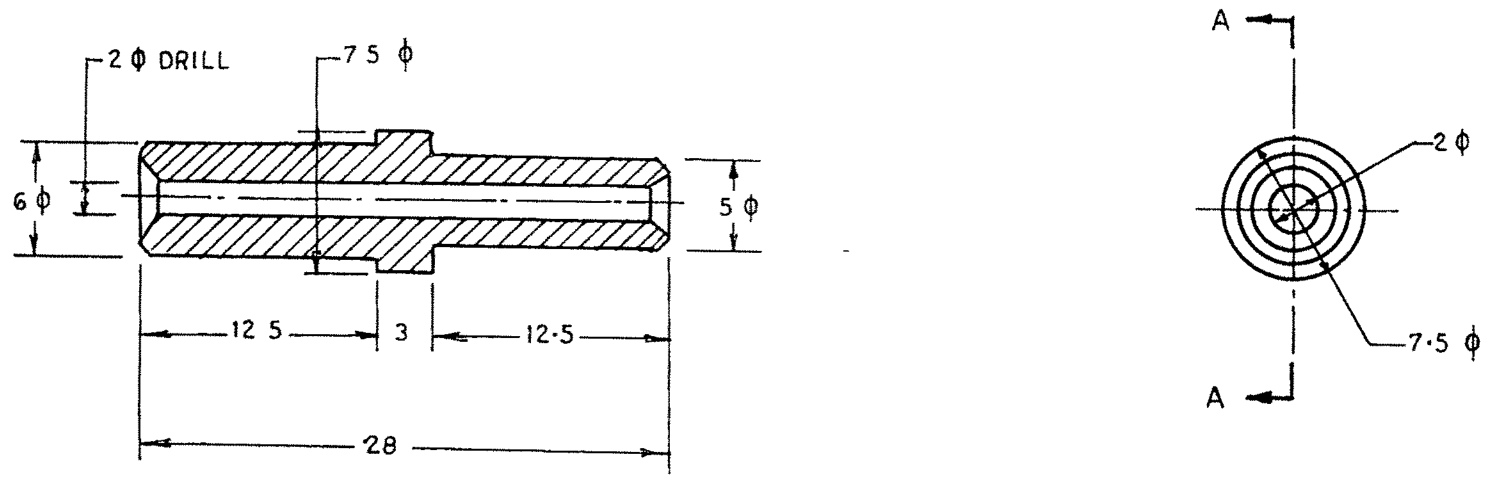
Performance of the straight grooved and inclined grooved spinning discs were compared in terms of minimum power consumption, more uniformity of distribution and better atomization The straight grooved spinning disc performed better by producing droplets of lesser sizes in all the liquid flow rates and spinning disc speeds Hence the straight grooved plastic spinning disc of 98 mm OD was used

e. Liquid line

The bottom opening of the liquid tank was connected to the spinning disc by a 6 mm I D plastic hose which was taken inside through the handle A connector to the dripping nozzle with 1.5 mm bore was made of gun metal, Fig 3 6, and held in position in the hole leading to the dripping nozzle of the spinning disc

f. Frame

The knapsack frame (without the engine and blower) of the power knapsack sprayer was used Provisions were made in the frame to hold the liquid tank and battery, Fig 3 7 A cut-off valve was fixed to the frame to stop the flow of fluid when desired



FRONT VIEW (SECTION ON AA)

SIDE VIEW

FIG.3.6 CONNECTOR TO DRIPPING NOZZLE

SCALE : 2 5:1

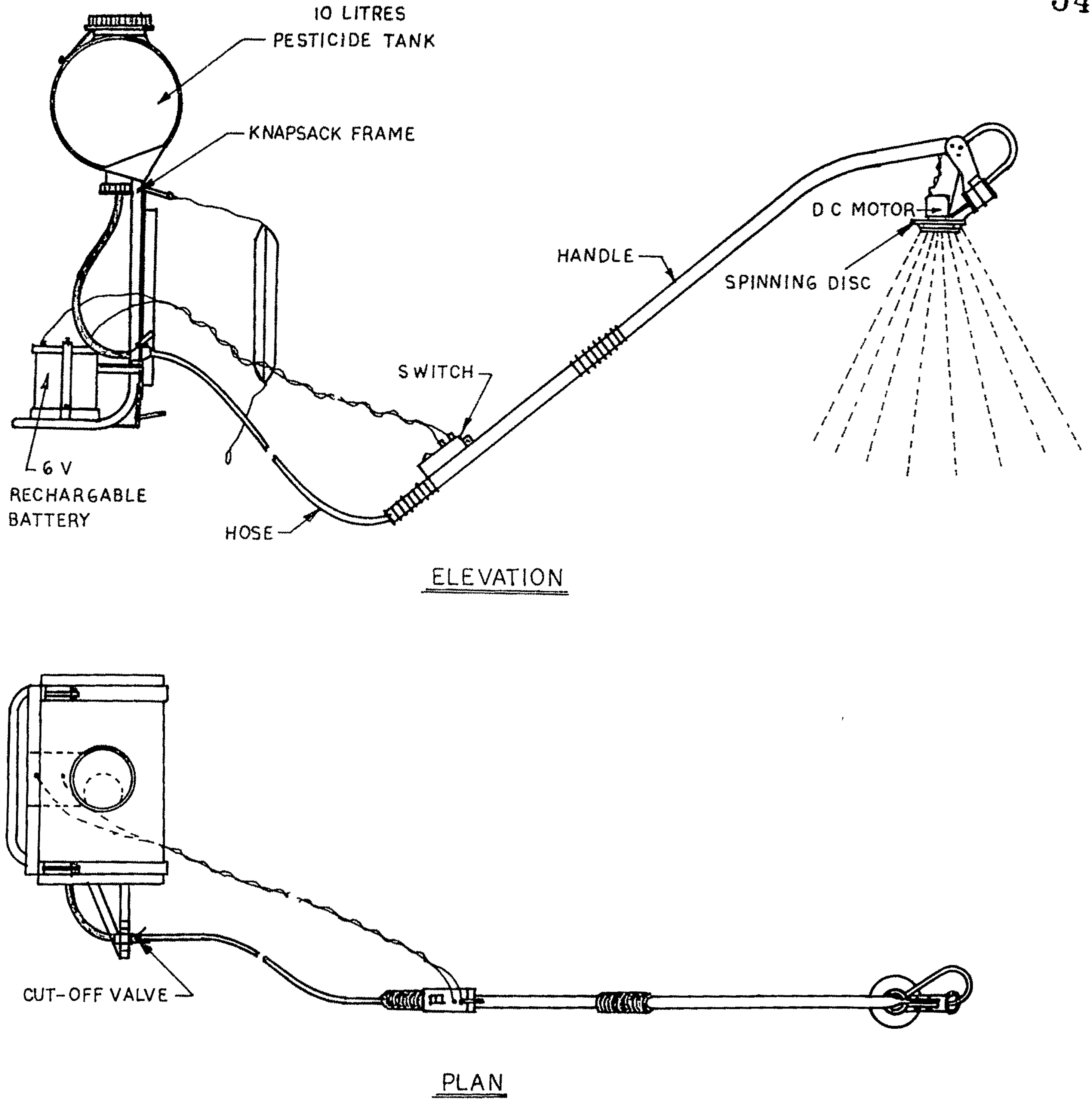


FIG.3.7 BATTERY POWERED PROTOTYPE SPINNING DISC SPRAYER

3.5. Performance characteristics of the prototype spinning disc sprayer

Tests were conducted with the prototype spinning disc sprayer to assess the power consumption, atomization characteristics and the energy release pattern of battery Sound level produced by the sprayer was also measured in comparison with power knapsack sprayer and battery powered pneumatic spraying system

3.5.1. Power consumption

The prototype sprayer was operated under no load at the voltage range of 4 to 6 V at 0 5 V interval At each voltage level, amperage reading was taken and the rotational speed of spinning disc was measured The test was repeated under load Power consumption of the motor was found under no load and load at different voltage levels

3.5.2. Atomization characteristics

The sprayer was operated at the same voltage range and interval with full flow rate of 150 cc min^{-1} as mentioned in section 3 5 1 The methylene blue dyed spray droplets were captured for 10 s duration on the 40 x 40 mm size glazed bromide papers placed at 500 mm vertical distance and at 600,800 and 1000 mm horizontal distances from the spinning disc centre Using the stain diameters on the sample cards, VMD and NMD of the spray spectra were computed

3.5.3. Energy release pattern of battery

The sprayer was operated at 150 cc min^{-1} flow rate with a fully charged 6 V, 5A h lead-acid battery continuously until the motor ceased to rotate After every one hour of operation, battery voltage, motor amperage and spinning disc speed were measured

3.5.4. Sound level measurement

Sound level produced by the prototype spinning disc sprayer was measured using a decibel meter in comparison with power knapsack sprayer and battery powered pneumatic spraying system The sound level measurements were taken at every 1 m radial distance from the source of sound emission until the sound level reading became constant

3.6. Field performance of the prototype spinning disc sprayer

A field experiment was conducted, Plate 9, to find the biological efficacy of the prototype spinning disc sprayer in comparison with power knapsack sprayer The details of treatments for the field experiment were as follows

3.6.1. Treatments

T_1 - Spraying with prototype spinning disc sprayer

T_2 - Spraying with Aspee make power knapsack sprayer

T_3 - Spraying with Hymatic make power knapsack sprayer

T_4 - Untreated check

Crop	-	Cotton, variety MCU 11
Design	-	Exploded design
Replications	-	Five
Age of the crop	-	Three months and 19 days

Plate 9. Field operation with battery powered prototype spinning disc sprayer

Insecticide	-	Methyl demeton (Metasystox) 750 cc of 25 EC (187 5 g ai)/ha
Location	-	Field number 69 of Eastern Block, Central Farm, Tamil Nadu Agricultural University, Coimbatore

3.6.2. Observations

Precount of insect population, cotton leaf hopper *Empoasca devastens* on three leaves at top, middle and bottom levels in each plant at 10 randomly selected plants in each plot of 12 5 x 10 0 mm was carried out

Post-count of leaf hopper population on 1,4,7 and 14 days after spraying was done as mentioned for pre-count

3.6.3. Biological efficiency

Biological efficiency (T) was determined by the following Henderson - Tilton equation (Zeren and Moser, 1988)

$$T = \{ 1 - (\frac{Ts\ Ce}{Te\ Cs}) \} 100 \qquad (3\ 3)$$

where Ts = counting on the experimental plots after spraying

Te = counting on the experimental plots before spraying

Ce = counting on the control plots after spraying

Cs = counting on the control plots before spraying

3.7. Cost - economics

Operational cost of the prototype spinning disc sprayer was determined as per the procedure described by the Bureau of Indian Standards (IS 9164-1979) in comparison with power knapsack sprayer Depreciation, interest on investment, repairs and maintenance, fuel and oil charges and operators wages were considered for calculating the operational cost The effective field capacity and operational cost were workedout and compared

CHAPTER IV

RESULTS AND DISCUSSION

Results of the experiments conducted under this investigation are presented and discussed in the following main headings

a Performance of spray patternator
b Determination of spread factor
c Effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics
d Development of battery powered prototype sprayer
e Performance characteristics of prototype sprayer
f Field performance evaluation of prototype sprayer
g Cost economics of prototype sprayer

4.1. Performance of spray patternator

The spray patternator was developed as per the specifications of Bureau of the Indian Standards Performance of the spray patternator was evaluated with the help of a rocker sprayer using hollow cone nozzle, Table 4 1

Total volume of spray liquid collected in the measuring glass tubes of the spray patternator when one litre was used in the test were 987, 992 and 995 cc for the three repetitive tests conducted Maximum deviation of the total spray volume collected was 0 44 per cent of the mean value Spray distribution pattern curves for the three tests are shown in Fig 4 1 Spray swath width of the nozzle was found from the spray pattern curves as 735, 750 and 728 mm for the three tests Corresponding spray

Table 4.1. Performance of spray patternator

Sl no	Channel no	Honzontal distance from nozzle (mm)	Spray volume (cc)			Mean
			1	2	3	
1	-13	-390	9	7	6	7 33
2	-12	-360	16	16	17	16 33
3	-11	-330	25	26	27	26 00
4	-10	-300	30	33	33	32 00
5	- 9	-270	41	40	42	41 00
6	- 8	-240	47	44	44	45 00
7	- 7	-210	54	57	54	55 00
8	- 6	-180	49	51	50	50 00
9	- 5	-150	48	50	50	49 33
10	- 4	-120	45	43	43	43 67
11	- 3	- 90	47	49	46	47 33
12	- 2	- 60	41	45	43	43 00
13	- 1	- 30	40	42	38	40 00
14	0	0	39	41	43	41 00
15	1	30	45	42	44	43 67
16	2	60	55	57	60	57 33
17	3	90	55	57	56	56 00
18	4	120	62	60	60	60 67
19	5	150	61	59	60	60 00
20	6	180	55	54	55	54 67
21	7	210	40	41	43	41 33
22	8	240	30	30	28	29 33
23	9	270	26	23	25	24 67
24	10	300	17	19	20	18 67
25	11	330	10	6	8	8 00
		Total	987	992	995	991 33

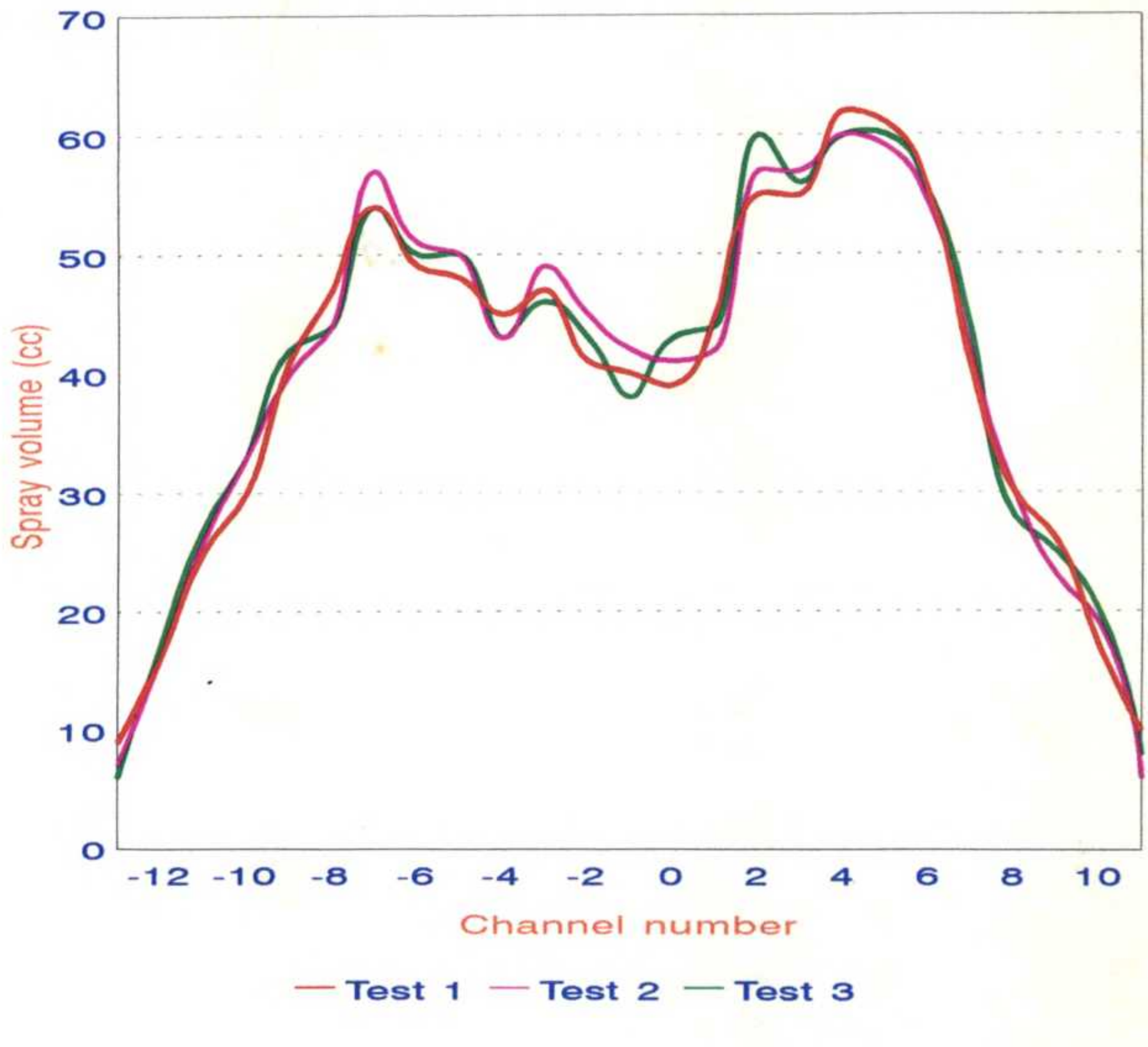


Fig. 4.1 Performance of spray patternator

angles were 72 63°, 73 74° and 71 89° respectively Coefficient of variation for the mean values was calculated to be 39 34 per cent

The spray pattern curves were close to each other which shows that the spray patternator could give uniform and consistent readings Hence the spray patternator was used for all the tests in the investigation to find the spray distribution pattern of different types of battery powered spraying systems and to compare the uniformity of spray volume distribution in terms of coefficient of variation

4.2. Determination of spread factor

One division of ocular micrometer in the microscope was calibrated to 17 60 µm, Table 4 2 Using the narrow spectrum droplet generator, the mean spread factor for methylene blue-glazed bromide paper combination was determined to be 0 645, Table 4 3

As the stain diameter increased, spherical droplet diameter increased, Fig 4 2 The mean rate of increase in spherical droplet diameter per unit increase in stain diameter was found to be 0 403 The mean spread factor of 0.645 was used to determine the spray droplet diameter from spread diameter of stains sampled on glazed bromide papers throughout this investigation

Table 4.2. Calibration of ocular micormeter in microscope

Sl no	Coinciding ocular micrometer divisions	Ocular divisions	Stage micrometer divisions (µm)	One ocular division (µm)
1	25,42	17	30	17 647
2	17,34	17	30	17 647
3	23,35	12	21	17 500
4	11,25	14	25	17 857
5	21,40	19	33	17 368
			Mean	17 60

Table 4.3. Determination of spread factor for methylene blue-glazed bromide paper combination

Liquid flow rate 57 cc min^{-1}

Sl no	Voltage (V)	Spinning disc speed	Ocular divisions (mean of 50)		Mean spherical droplet dia	Mean stain dia	Spread factor
		(rev min^{-1})	Petridish	Bromide paper	(µm)	(µm)	
1	4 0	2584	17 20	28 10	302 72	494 56	0 612
2	4 5	2765	16 24	25 98	285 82	457 25	0 625
3	5 0	3063	15 40	23 65	271 04	416 24	0 651
4	5 5	3346	15 14	22 80	266 46	401 28	0 664
5	6 0	3532	14 64	21 75	257 66	382 80	0 673
						Mean	0 645

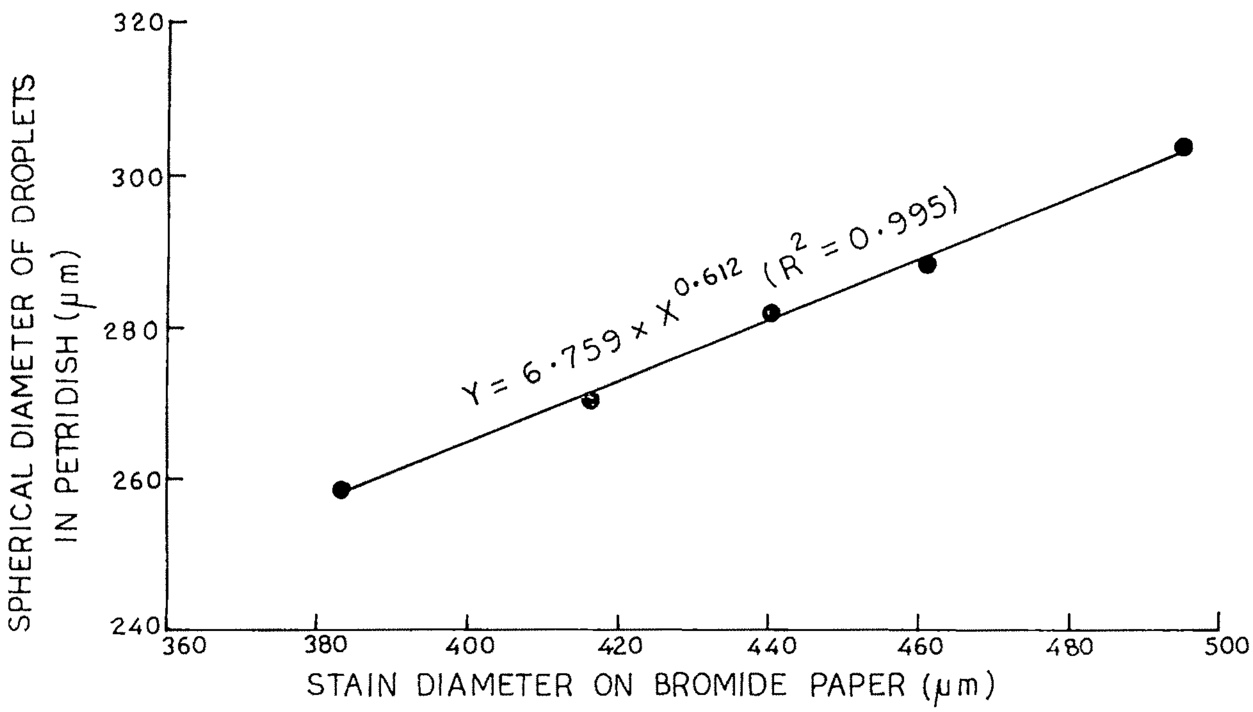


FIG. 4.2 SPREAD FACTOR CURVE FOR METHYLENE BLUE-BROMIDE PAPER COMBINATION

4.3 Effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics

Results of tests conducted to study the effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics of battery powered hydraulic, pneumatic and centrifugal spraying systems are presented and discussed under this section

4.3.1. Battery powered hydraulic spraying system

Components of power consumption were found for the spraying system at varying voltage Experimental data collected to study the effect of liquid pressure on spray distribution pattern and atomization characteristics of the system are presented and discussed Energy release pattern of battery for the system are also presented and discussed

a. Components of power consumption

Components of power consumption for self-running of the DC motor, for operating the gear pump and pumping liquid to develop the spray pressure at different voltage levels are shown in Table 4 4 When operated at the rated 12 V, power consumption for self-running of the motor was 12 W with 1940 rev min^{-1} rotational speed Power consumption for operating the gear pump at no load was 24 48 W with 1818 rev min^{-1} speed and that for operating the gear pump at load was 53 16 W with 1389 rev min^{-1} speed For operating the gear pump, 12 48 W power was expended and for liquid pumping alone, 26 68 W power was expended at the rated 12 V

Table 4.4. Components of power consumption for hydraulic spraying system

Sl no	Voltage (V)	Without gear pump			With gear pump at no load			With gear pump at load		
		Current (A)	Power (W)	Speed (rev min^{-1})	Current (A)	Power (W)	Speed (rev min^{-1})	Current (A)	Power (W)	Speed (rev min^{-1})
1	6	0 73	4 38	950	1 96	11 76	774	1 98	11 87	584
2	7	0 78	5 46	1140	1 97	13 79	959	2 43	17 03	752
3	8	0 81	6 48	1323	1 99	15 92	1125	2 75	22 00	927
4	9	0 86	7 74	1515	2 00	18 00	1294	2 99	26 91	1062
5	10	0 90	9 00	1680	2 00	20 00	1494	3 39	33 90	1204
6	11	0 95	10 45	1830	2 04	22 44	1669	3 85	42 35	1272
7	12	1 00	12 00	1940	2 04	24 48	1818	4 43	53 16	1389

Power consumption varied linearly as the voltage increased at no load Power increased at an increasing rate at load as the voltage increased from 6 to 12 V, Fig 4 3 The mean rate of increase in power consumption per unit increase in voltage was 1 27 W without gear pump, 2 12 W with gear pump at no load and 6 88 W with gear pump at load

Reduction in rotational speed of the DC motor with gear pump at no load and load were 6 30 and 28 40 per cent respectively The rated speed of 1500 rev min^{-1} of the gear pump could not be achieved at the rated 12 V under load. Motor speed increased linearly as the voltage increased from 6 to 12 V at no load But at load, the speed increased at a constant rate upto 10V, beyond which the speed increased at a decreasing rate, Fig 4 4 The mean rate of increase in motor speed for unit increase in voltage was 174 rev min^{-1} at no load, 134 rev min^{-1} at load and 165 rev min^{-1} for motor alone

b. Effect of liquid pressure on spray performance

Results of experiments conducted to study the effect of liquid pressure on spray performance *viz*, spray distribution pattern, spray and atomization characteristics of the spraying system with hollow cone nozzle and flat fan nozzle are presented and discussed here

i Spray distribution pattern

Spray pattern test results of the spraying system with hollow cone nozzle and flat fan nozzle at 5 levels of liquid pressure (at 5 levels of voltage) are presented in

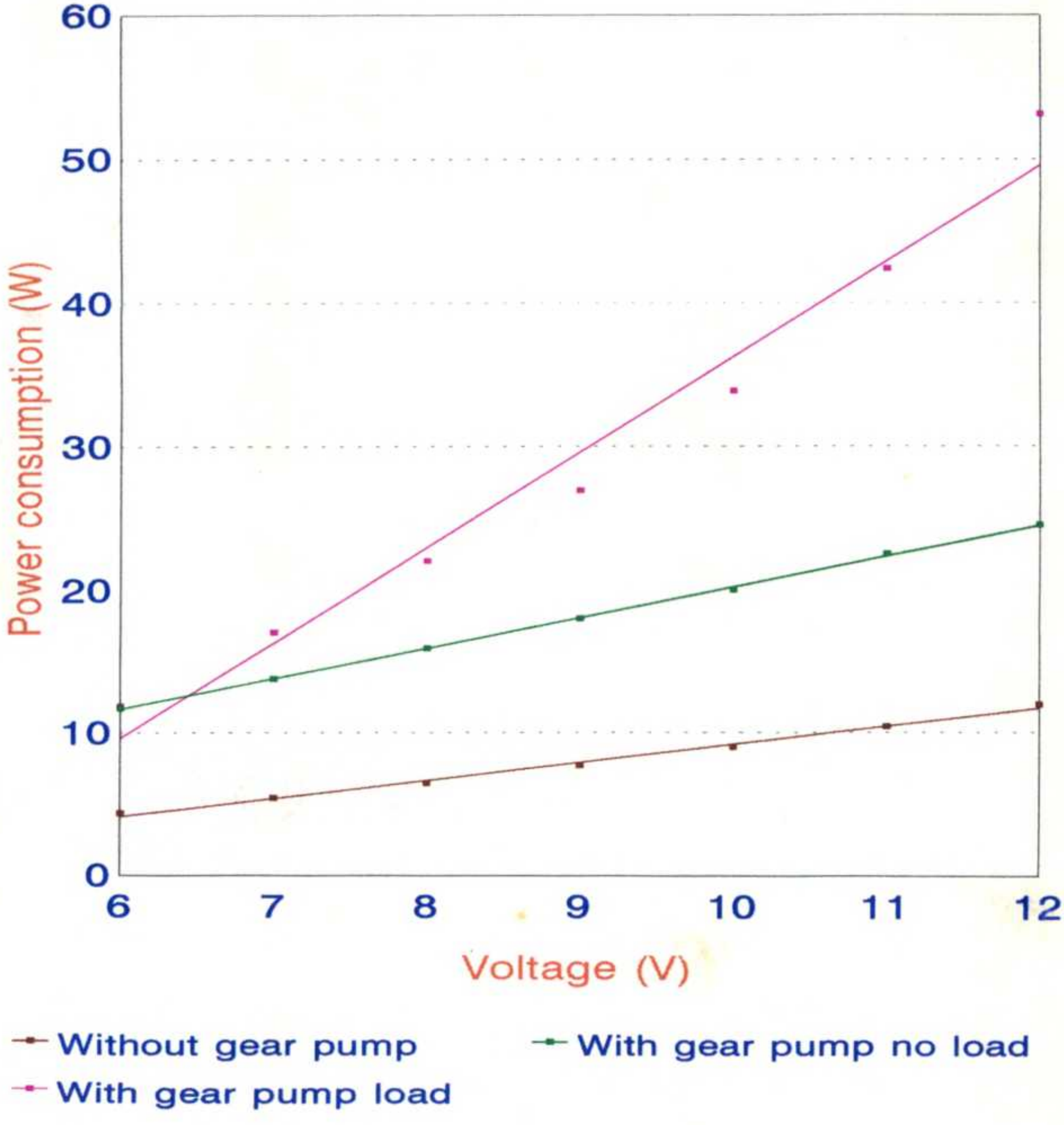


Fig. 4.3 Power consumption for hydraulic spraying system

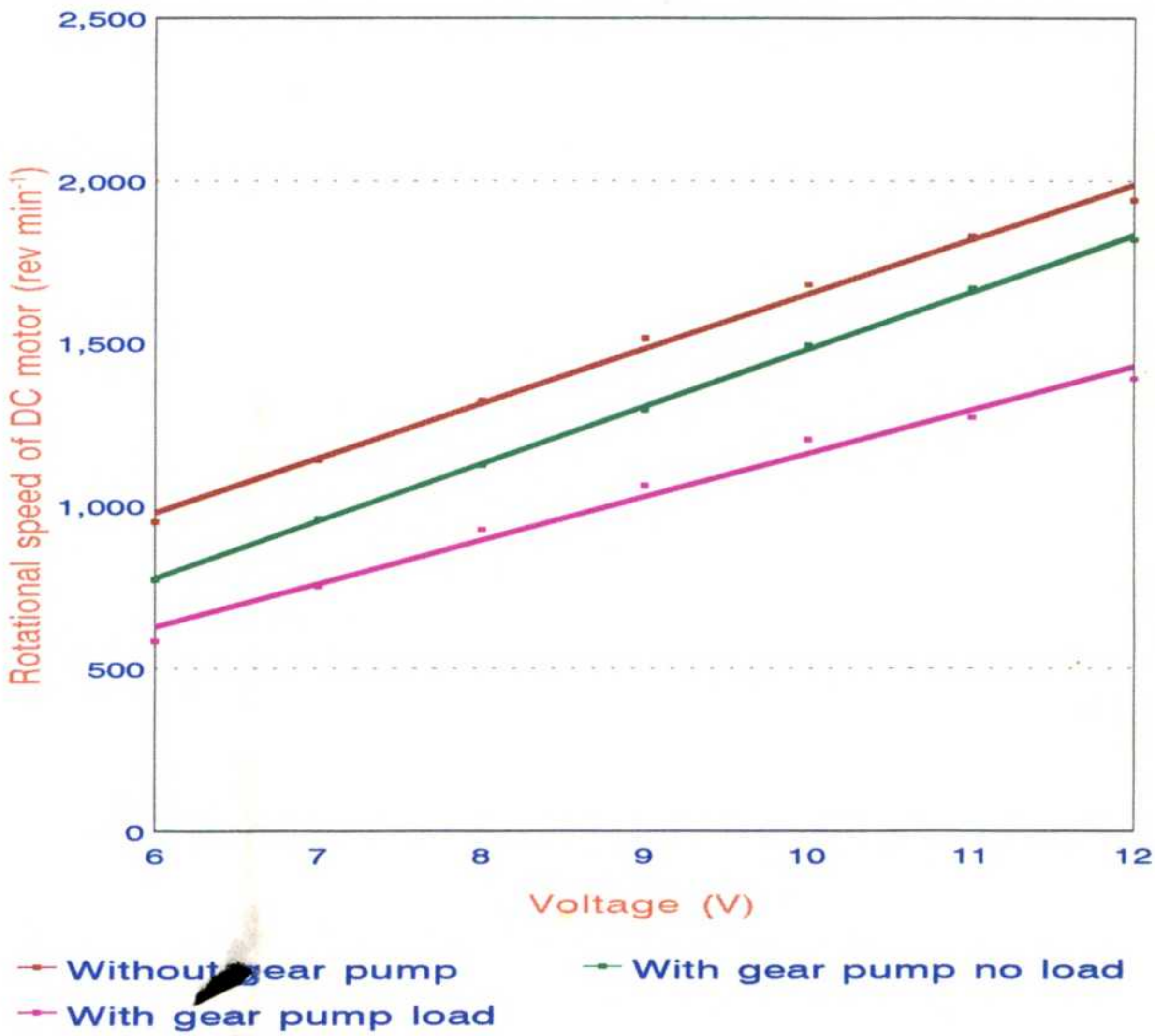


Fig. 4.4 Rotational speed of DC motor at varying voltage

Table 4 5 and Table 4.6 respectively As the liquid pressure increased from 44 to 113 kPa, peak of spray distribution pattern curves reduced from 142 to 93 cc in the case of hollow cone nozzle, Fig 4 5 In the case of flat fan nozzle, the above phenomenon was less pronounced, Fig 4 6. As the liquid pressure increased, the spray pattern curves broaden for both the nozzles Skewness of spray pattern curves towards one side for the hollow cone nozzle might be due to inadequate liquid pressure developed by the gear pump

As the liquid pressure was increased by increasing the voltage from 8 V to 12 V, coefficient of variation (CV) for the spray volume distribution reduced from 99 77 to 74 09 per cent for hollow cone nozzle and from 76 31 to 59 39 per cent for flat fan nozzle These results are in agreement with the results reported by Bode *et al* (1968) and Tajuddin *et al* (1978) that the spray pattern from cone and fan spray nozzles were more uniform as the liquid pressure increased

The CV values of 59 39 per cent and above for both the nozzles at all the levels of liquid pressure under test indicated the unacceptability of the spray distribution, since higher the CV, greater is the variation in the spray distribution (Azimi *et al* , 1985, Ozkan, 1987). CV's below 15 per cent indicate acceptable variation in coverage and biologically efficient while CV's above 15 per cent indicate unacceptable variation (Ayers *et al* , 1990, Ozkan *et al.*, 1992, Chapple *et al* , 1993)

The CV versus pressure curve of both hollow cone nozzle and flat fan nozzle tend to be asymptotic to abscissa, Fig 4 7 Hence by increasing the liquid pressure

Table 4.5. Effect of liquid pressure on spray distribution pattern for hollow cone nozzle

Sl no	Horizontal distance from nozzle (mm)	Mean spray volume (cc) Liquid pressure (kPa)				
		44 (8V)	59 (9V)	78 (10V)	98 (11V)	113 (12V)
1	-240	-	-	-	8 5	8 0
2	-210	-	-	6 0	14 5	13 0
3	-180	3 0	6 5	11 0	25 5	21 0
4	-150	9 5	16 5	26 0	49 0	33 5
5	-120	27 5	48 0	56 5	75 0	55 0
6	- 90	56 0	95 5	91 5	94 5	74 5
7	- 60	100 5	118 5	106 0	97 0	88 0
8	- 30	142 0	122 5	100 5	85 5	87 0
9	0	114 0	93 0	110 0	93 5	101 5
10	30	35 0	29 0	49 5	48 5	55 0
11	60	10 0	9 0	14 5	14 5	17 5
12	90	4 0	4 0	5 0	5 0	6 0
	CV (%)	99 77	88 76	81 63	77 10	74 09

Table 4.6. Effect of liquid pressure on spray distribution pattern for flat fan nozzle

Sl no.	Horizontal distance from nozzle (mm)	Mean spray volume (cc) Liquid pressure (kPa)				
		33 (8V)	38 (9V)	42 (10V)	45 (11V)	59 (12V)
1	-270	-	-	6	6	7
2	-240	-	5	14	11	10
3	-210	7	15	17	19	21
4	-180	12	26	52	57	61
5	-150	20	51	63	69	73
6	-120	33	74	78	83	90
7	- 90	55	95	81	87	92
8	- 60	75	97	75	81	87
9	- 30	88	84	71	77	91
10	0	87	97	57	63	72
11	30	102	93	50	55	58
12	60	54	65	43	52	53
13	90	15	49	36	41	51
14	120	6	15	25	29	46
15	150	-	8	10	11	37
16	180	-	-	5	7	17
17	210	-	-	-	-	8
	CV (%)	76 31	64 77	63 41	62 72	59 39

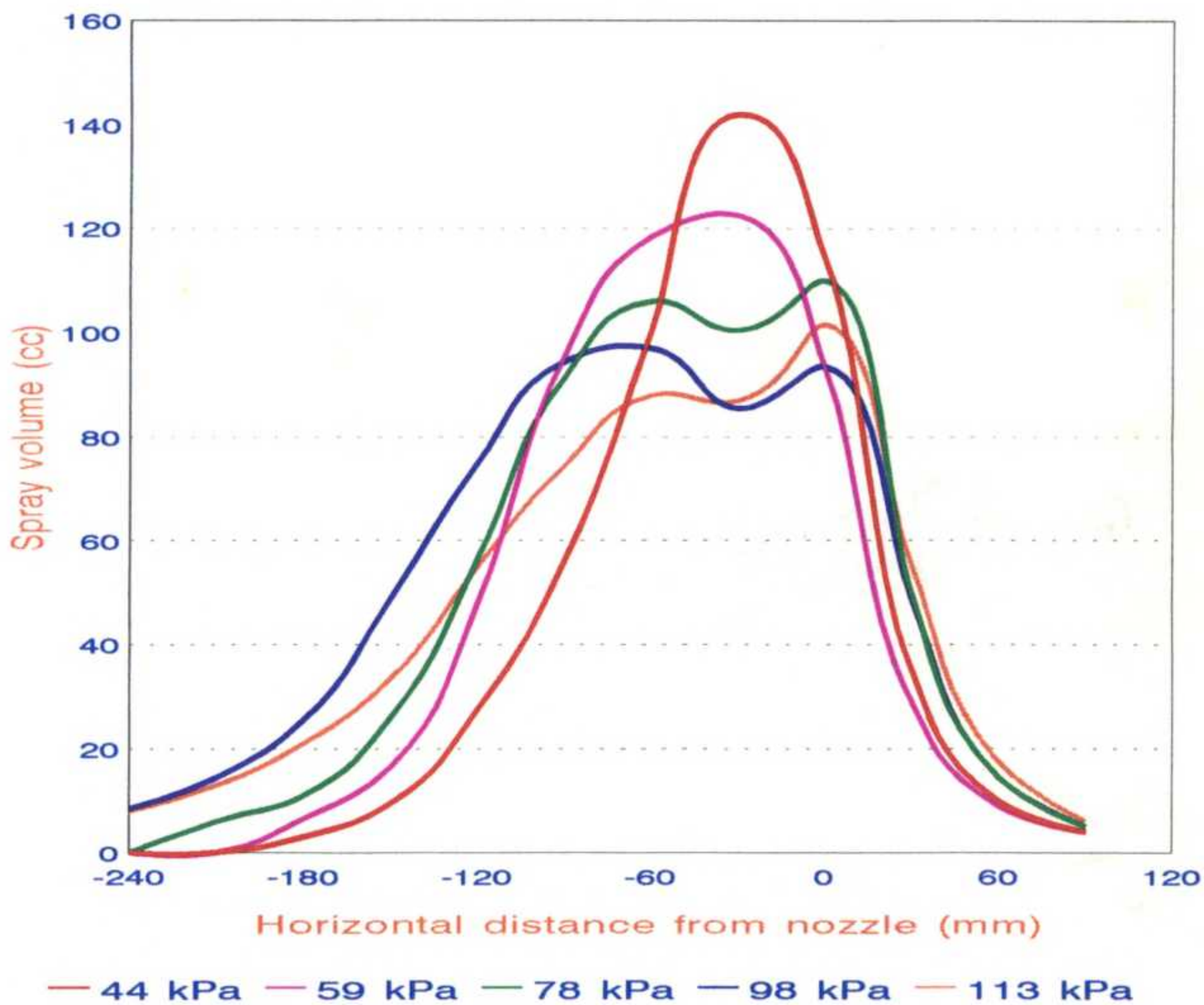


Fig. 4.5 Spray distribution pattern for hollow cone nozzle

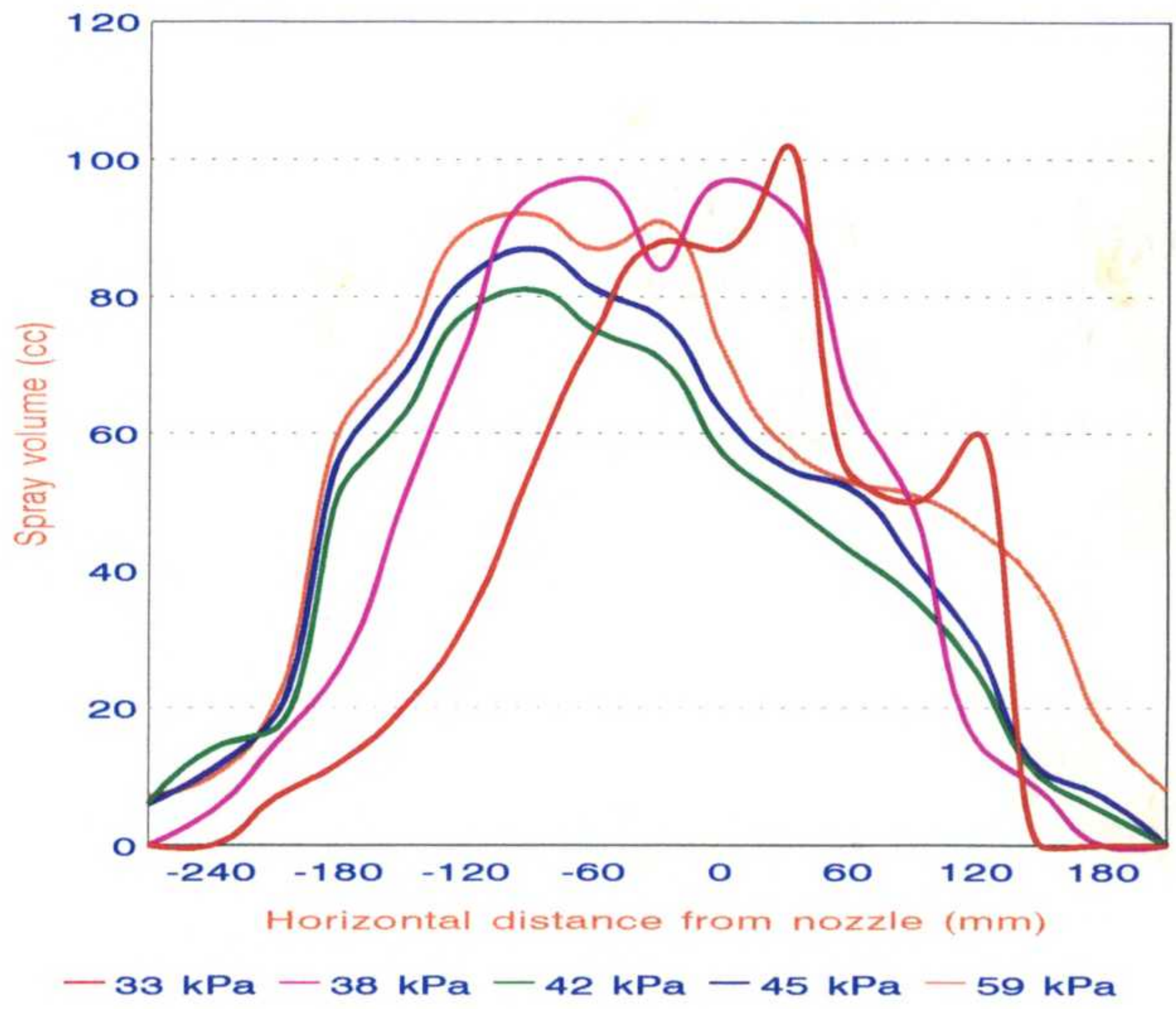
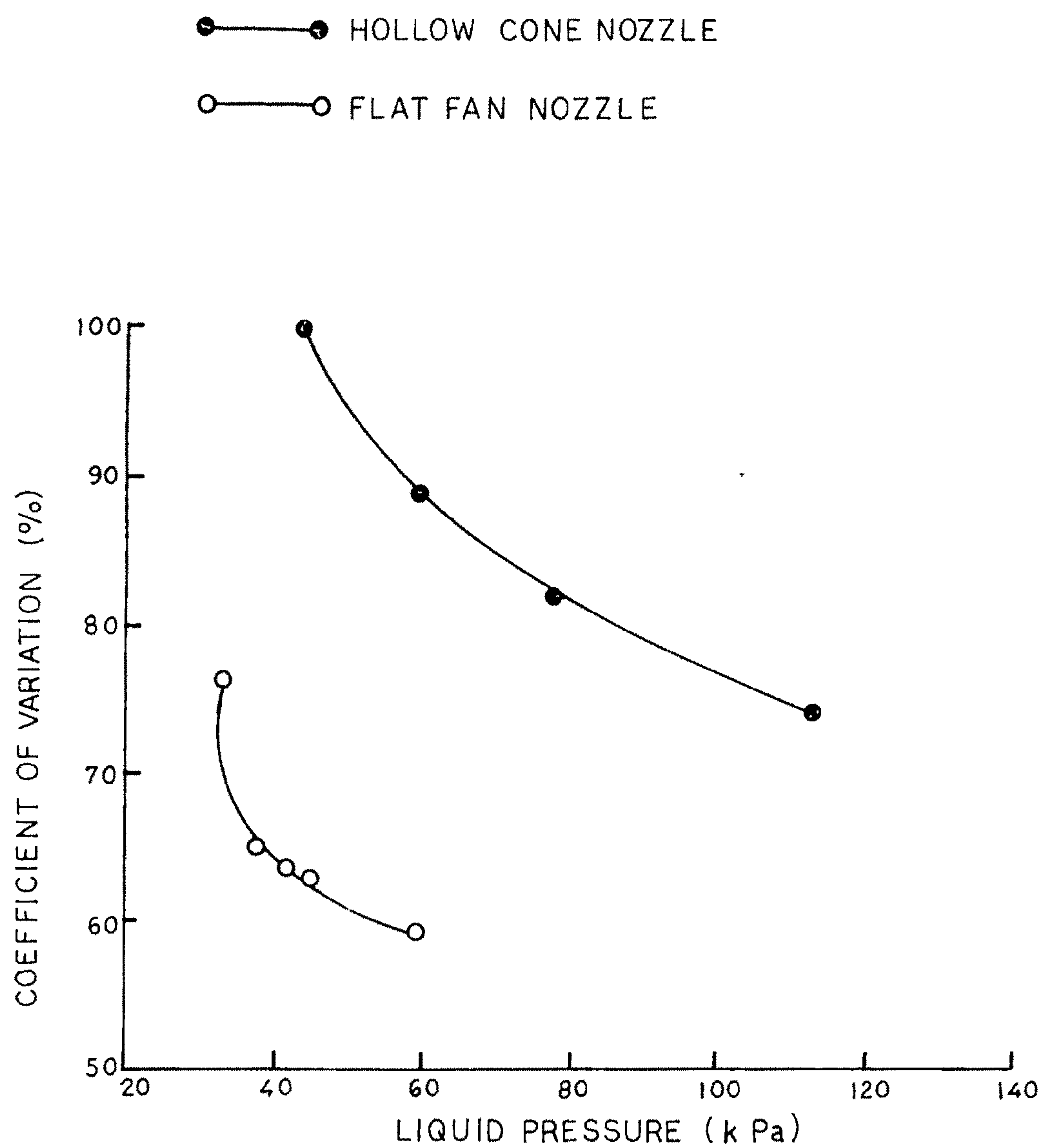


Fig. 4.6 Spray distribution pattern for flat fan nozzle



IG.4.7 EFFECT OF LIQUID PRESSURE ON COEFFICIENT OF VARIATION

beyond the maximum value obtained, CV cannot be decreased appreciably i e , the uniformity of spray volume distribution cannot be improved in the case of hydraulic spraying system

ii. Spray characteristics

Liquid flow rate, spray width and spray angle of the spraying system at 5 levels of liquid pressure for hollow cone nozzle and flat fan nozzle are given in Table 4 7 As voltage increased from 8 to 12 V, liquid pressure increased at a constant rate from 44 to 113 KPa for hollow cone nozzle and from 33 to 56 kPa for flat fan nozzle, Fig 4 8 As the liquid pressure increased in the above ranges, flow rate increased linearly from 220 to 310 cc min^{-1} for hollow cone nozzle and from 330 to 530 cc min^{-1} for flat fan nozzle, Fig 4 9

As liquid pressure increased from 44 to 79 kPa, spray width increased at a decreasing rate from 300 to 360 mm for hollow cone nozzle In the pressure range of 79 to 113 kPa, spray width increased at a constant rate from 360 to 367 5 mm, Fig. 4 10 In the case of flat fan nozzle, as pressure increased from 33 to 45 kPa, spray width increased at a decreasing rate from 390 to 525 mm Beyond 45 kPa pressure, rate of increase in spray width reduced Similar trend was observed for spray angle in the case of both the nozzles. These results conform the report of Bindra and Singh(1977) and Mathew *et al.* (1992) that increase in liquid pressure resulted in linear increase of liquid flow rate and spray angle

Table 4.7. Effect of liquid pressure on spray characteristics

Sl no	Voltage	Hollow cone nozzle				Flat fan nozzle			
	(V)	Liquid pressure (kPa)	Flow rate (cc min^{-1})	Spray width (mm)	Spray angle (deg)	Liquid pressure (kPa)	Flow rate (cc min^{-1})	Spray width (mm)	Spray angle (deg)
1	8	44 15	220	300 0	64 83	33 46	33 0	390 0	42 61
2	9	58 86	240	315 0	66 94	37 62	390	435 0	47 02
3	10	78 48	260	360 0	73 67	41 74	410	510 0	54 04
4	11	98 10	290	365 0	74 05	45.17	450	525 0	55 40
5	12	112 82	310	367 5	74 90	58 98	530	540 0	56 74

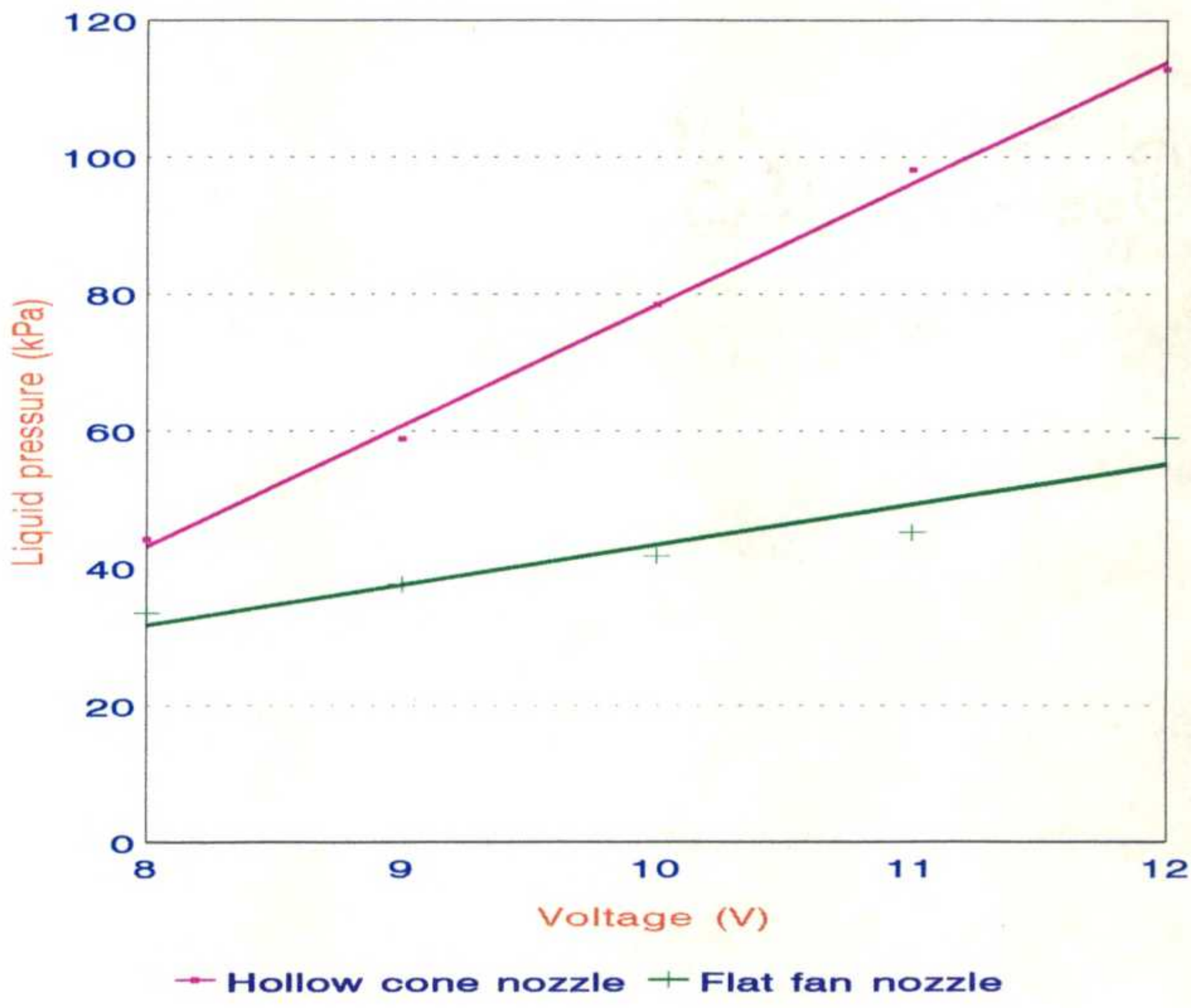


Fig. 4.8 Liquid pressure at varying voltage

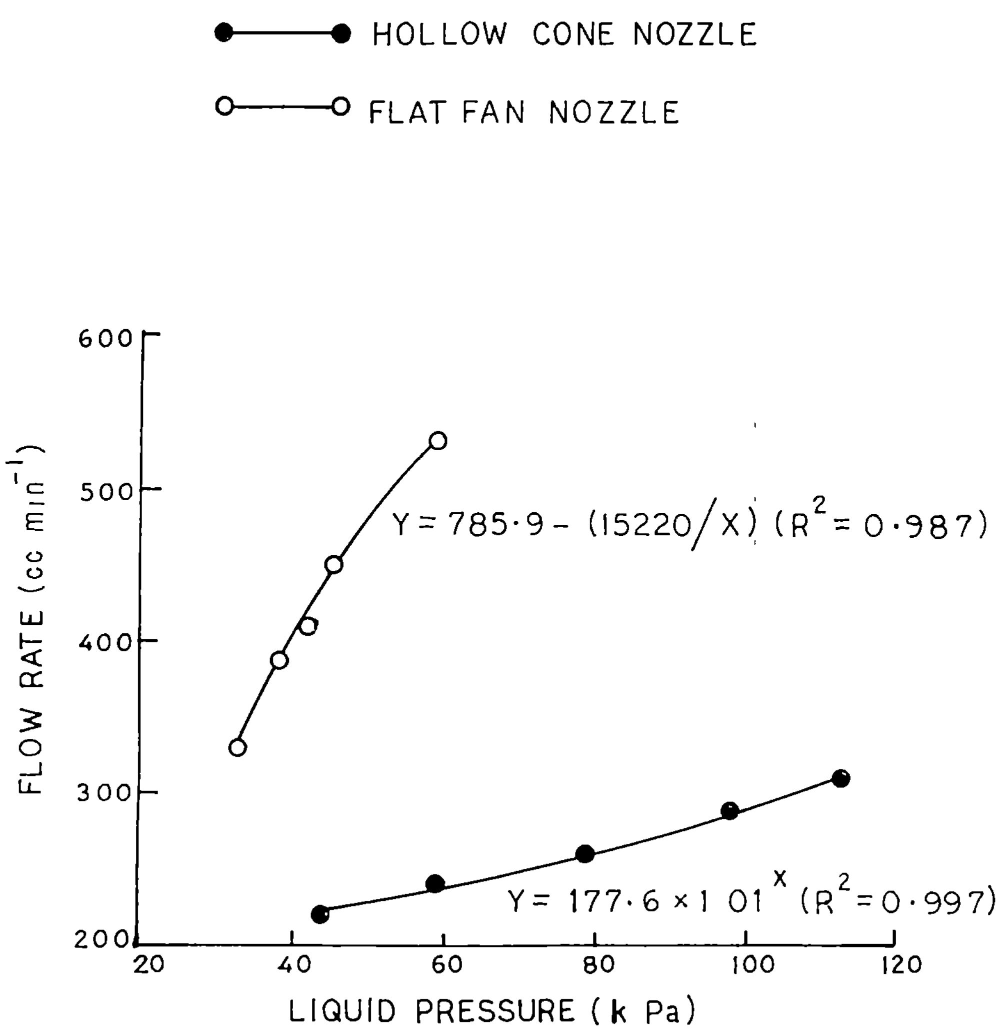


FIG.4.9 EFFECT OF LIQUID PRESSURE ON FLOW RATE

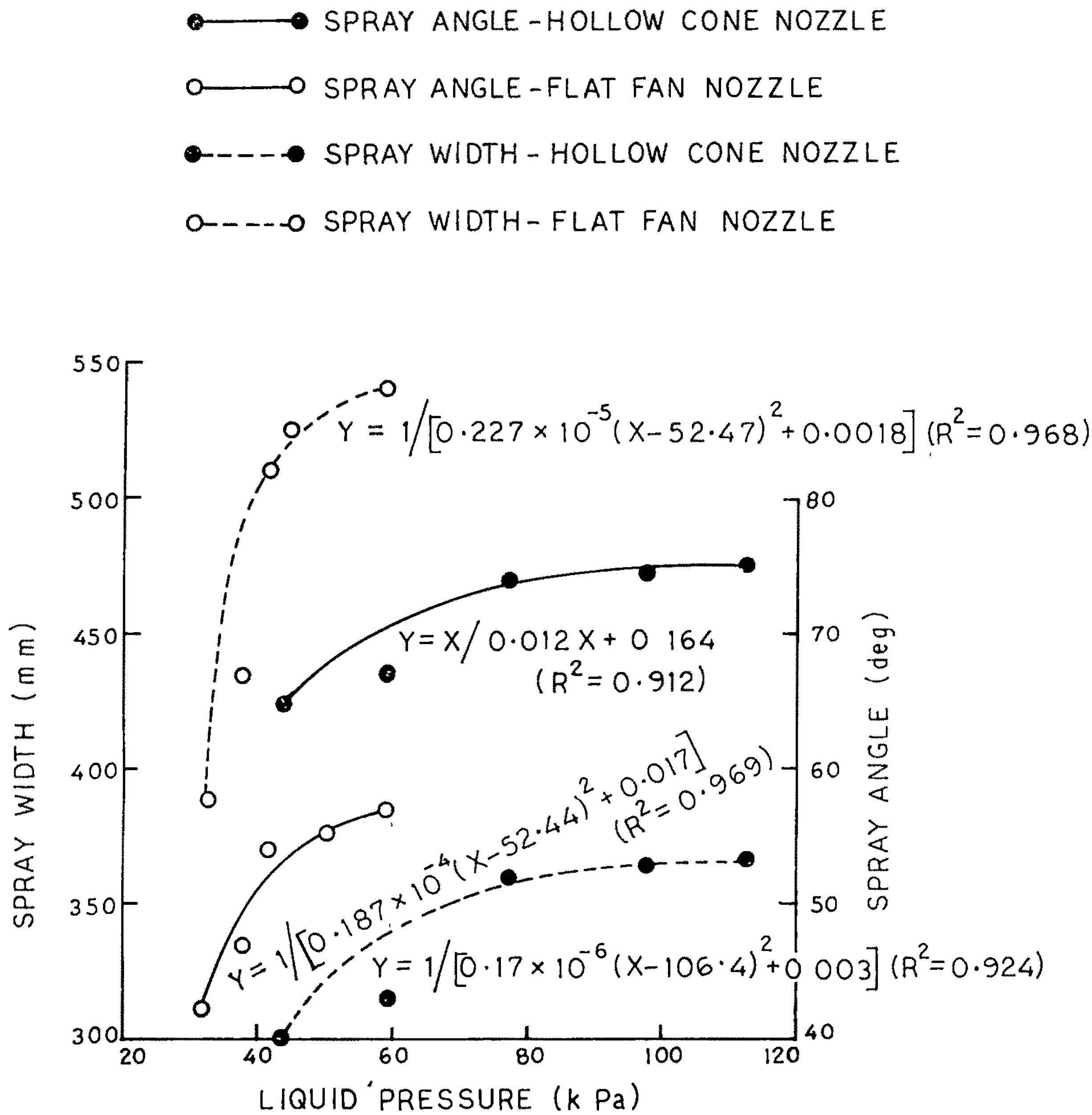


FIG. 4.10 EFFECT OF LIQUID PRESSURE ON SPRAY WIDTH AND SPRAY ANGLE

Liquid pressure, flow rate and spray angle for hollow cone nozzle were 112 82 kPa, 310 cc min^{-1} and 74 90° respectively at the rated 12 V, whereas the rated pressure, flow rate and spray angle for the nozzle are 275 95 kPa, 472 5 cc min^{-1} and 75° respectively For flat fan nozzle, pressure, flow rate and spray angle obtained at 12 V were 59 kPa, 530 cc min^{-1} and 56 7° respectively whereas the respective rated values are 69 kPa, 675 cc min^{-1} and 60°

iii. Atomization characteristics

VMD and NMD of the spraying system with hollow cone nozzle and flat fan nozzle at 5 levels of liquid pressure are given in Table 4 8

As liquid pressure increased from 44 to 113 kPa, VMD reduced from 307 to 242 μm, NMD reduced from 250 to 219 μm and VMD NMD ratio reduced from 1 199 to 1 106 for hollow cone nozzle As liquid pressure increased from 33 to 59 kPa, VMD reduced from 397 to 317 μm, NMD from 317 to 262 μm and VMD NMD ratio from 1 253 to 1 195 for flat fan nozzle These results are in conformity with Smith and Wilkes (1977) and Mathew *et al* (1992) who found that increasing liquid pressure in hydraulic sprayer decreased spray droplet size

As pressure increased, both VMD and NMD decreased at a decreasing rate for both hollow cone and flat fan nozzles, Fig 4 11 As the pressure increased, uniformity of droplet size distribution increased for both the nozzles, which is revealed by reduction in the uniformity coefficient of dropsize distribution i.e., the VMD NMD ratio

Table 4.8. Effect of liquid pressure on atomization characteristics

Ambient Temperature 28°C(db)
Relative humidity 58 5 per cent

Sl no	Hollow cone nozzle				Flat fan nozzle			
	Liquid pressure (kPa)	VMD (µm)	NMD (µm)	VMD/NMD	Liquid pressure (kPa)	VMD (µm)	NMD (µm)	VMD/NMD
1	44 15	307 03	256 02	1 199	33 46	397 40	317 20	1 253
2	58 86	290 56	243 75	1 192	37 62	375 65	301 57	1 246
3	78 48	256 47	225 85	1 136	41 74	346 74	281 84	1 230
4	98 10	244 37	220 69	1 108	45 17	331 53	271 70	1 220
5	112 82	242 03	218 79	1 106	58 98	313 36	262 31	1 195

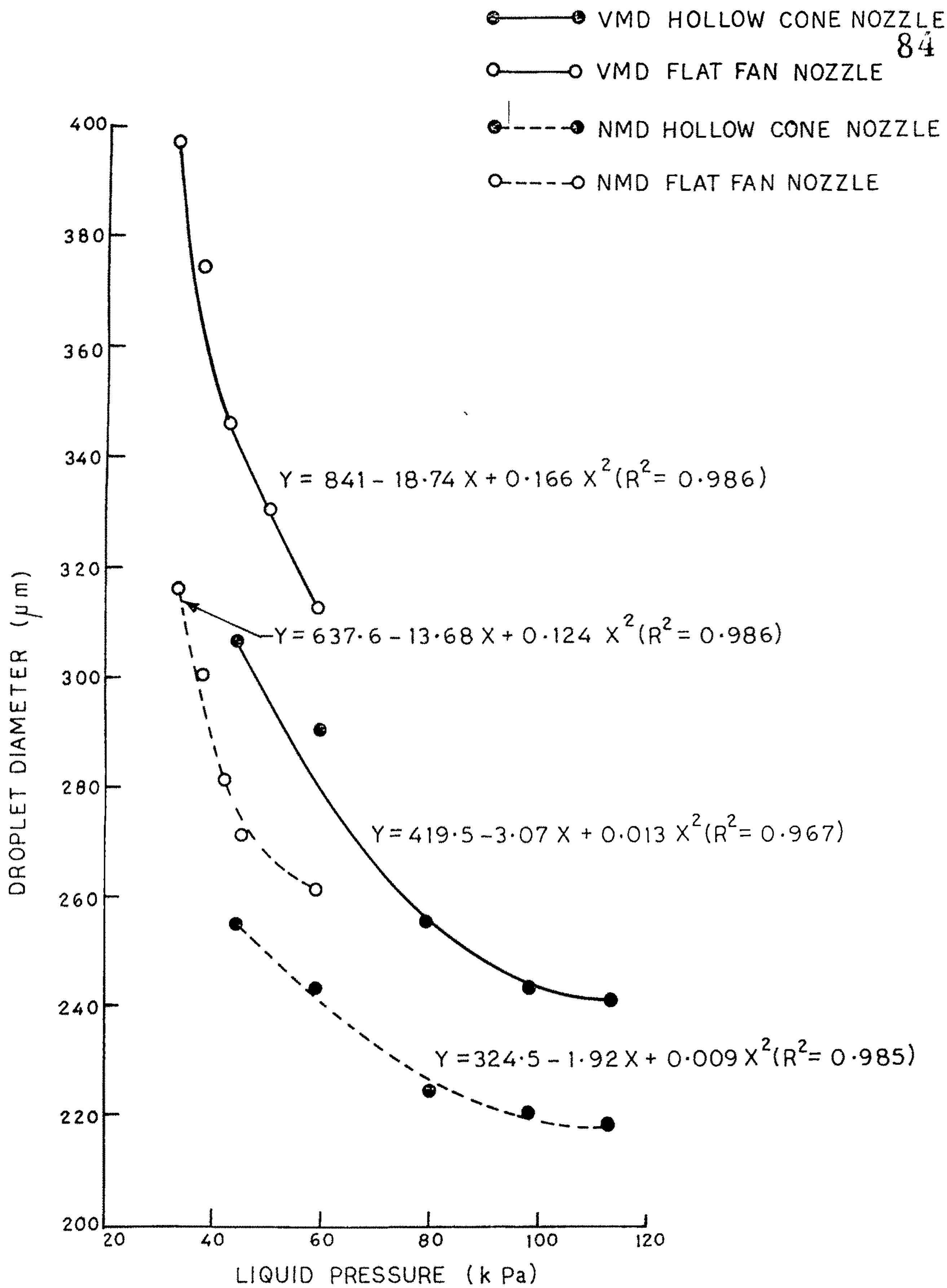


FIG.4.11 EFFECT OF LIQUID PRESSURE ON ATOMIZATION CHARACTERISTICS

towards unity, Fig 4 12 Visual observation of the stained bromide papers revealed that variation in droplet size was more pronounced at all the operating pressures

c. Energy release pattern of battery

Battery voltage, pump speed, liquid pressure and flow rate of the spraying system at every 10 min intervals when operated continuously with battery are given in Table 4 9

Table 4.9. Energy release pattern of battery for hydraulic spraying system

Sl no	Operating time (min)	Battery voltage (V)	Pump speed (rev min^{-1})	Liquid pressure (kPa)	Flow rate (cc min^{-1})
1	0	12 00	103 0	300	1444
2	10	11 00	98 1	296	1412
3	20	10 75	93 2	290	1375
4	30	10 00	73 6	260	1262
5	40	6 25	14 7	170	760

At 50^{th} min of operation, the DC motor ceased to rotate The spraying system could be effectively operated only for 30 min duration, Fig 4 13 Beyond 30 min, battery voltage suddenly dropped down to 6 3 V within 10 min of operation Pump speed reduced at a constant rate from 1400 to 1250 rev min^{-1} in the range of 0 to 30 min operating time, beyond which the pump speed came down to 750 rev min^{-1}

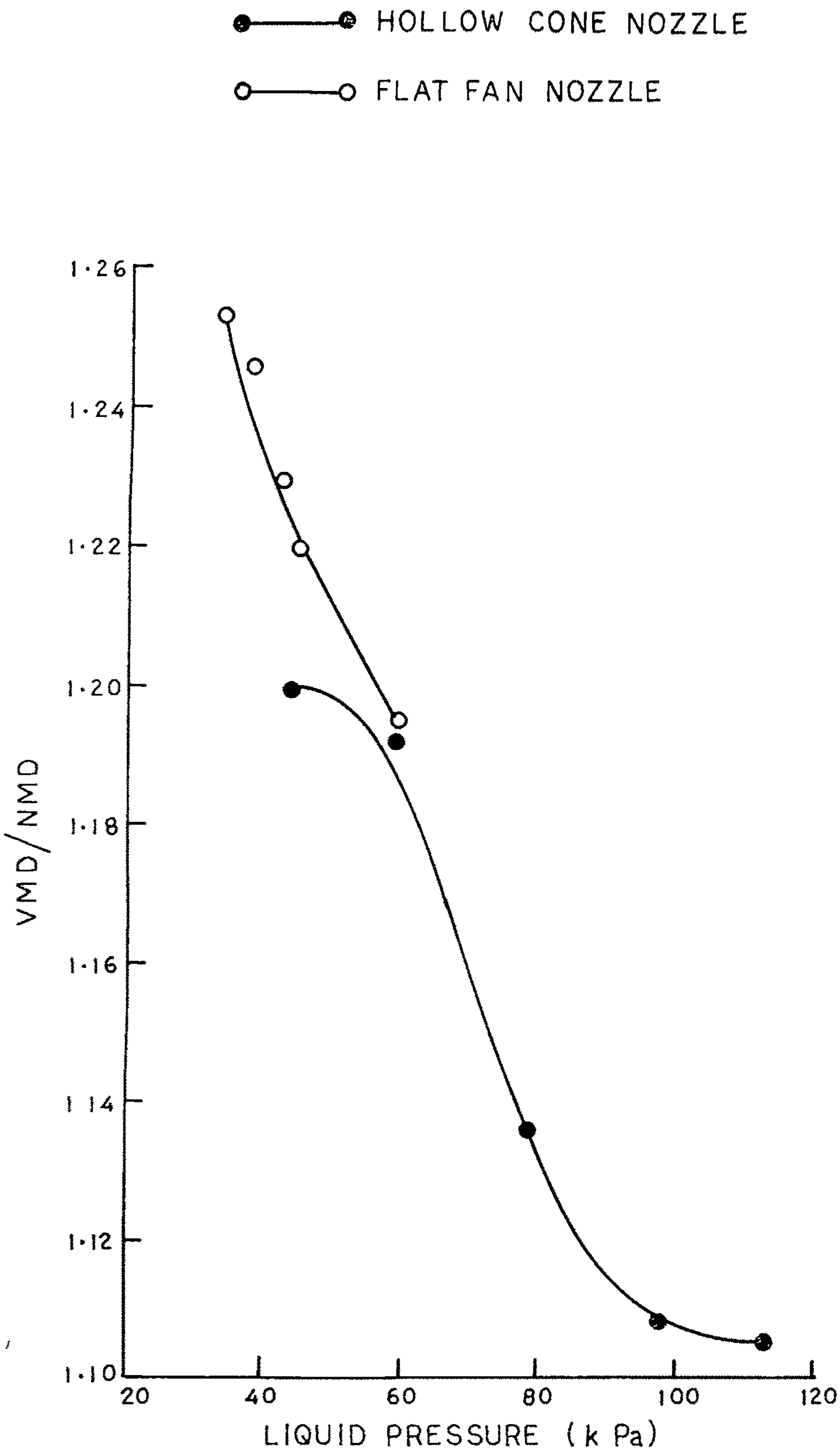


FIG. 4.12 EFFECT OF LIQUID PRESSURE ON VMD/NMD RATIO

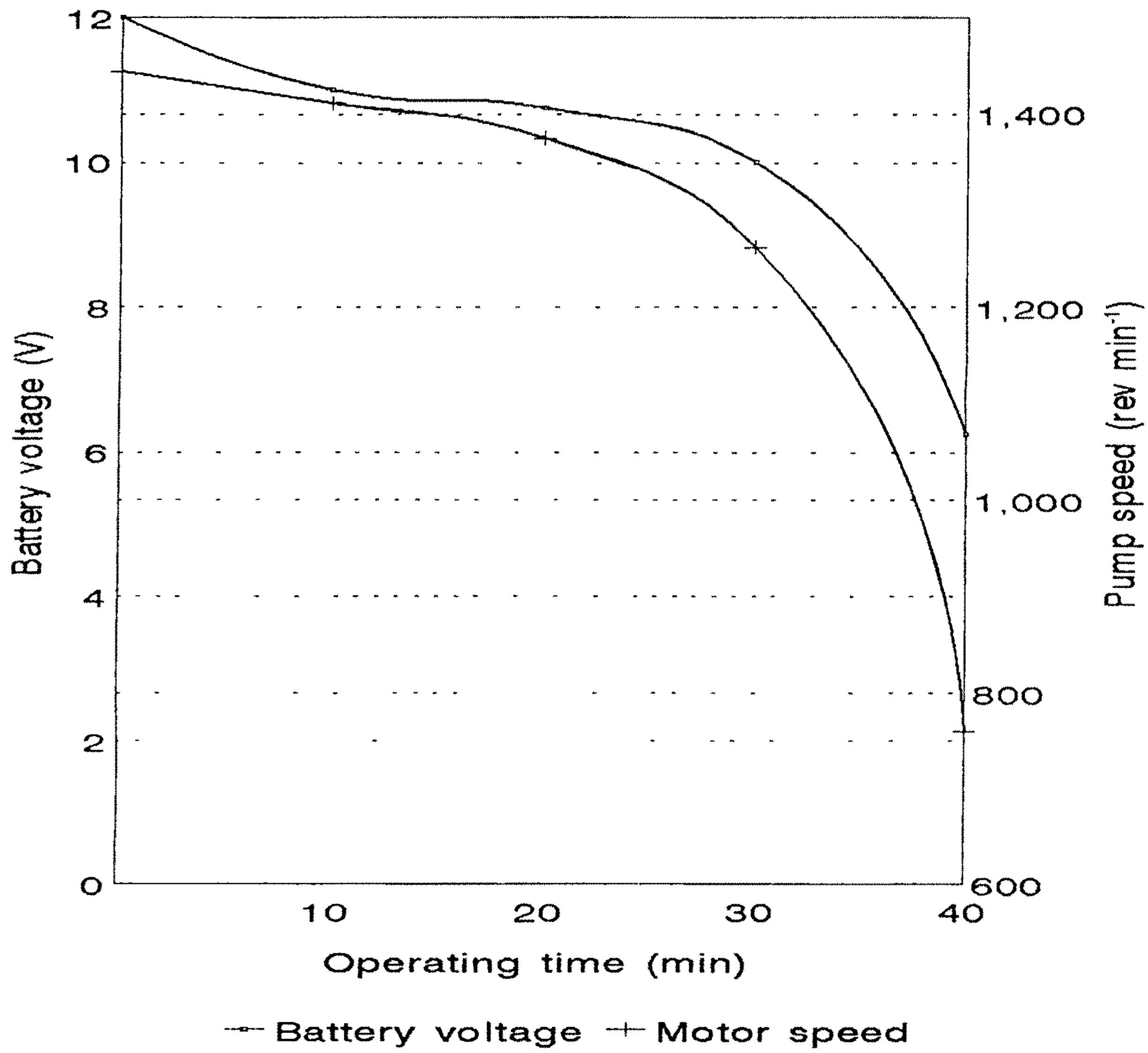


Fig. 4.13 Energy release pattern of battery for hydraulic spraying system

In the 0 to 30 min time range, liquid pressure dropped from 103 to 73 kPa and flow rate from 300 to 260 cc min^{-1}, Fig 4 14 In the 30-40 min time range, the pressure reduced from 73 to 15 kPa flow rate from 260 to 170 cc min^{-1} Comparison of Fig 4 11 and Fig 4 14 revealed that in the operating pressure range of 73 to 103 kPa, VMD ranged from 270 to 244 μm and NMD from 233 to 220 μm In this pressure range, change in drop size was minimum Below 73 kPa pressure, change in drop size was more pronounced

4.3.2. Battery powered pneumatic spraying system

Power consumption of the spraying system was experimentally found at varying voltage Data collected to study the effect of air velocity on spray distribution pattern and atomization characteristics of the system are presented and discussed Energy release pattern of battery for the system has also been presented and discussed here

a. Power Consumption

Power consumption of the system at varying voltage levels from 12 to 24 V are given in Table 4 10 Rotational speed of the blower and the air velocity at the corresponding voltage levels are also given in the Table 4 10

Power consumption of the DC motor increased from 18 72 W at 12 V to 63 12 W at 24 V of the motor. Correspondingly the rotational speed of the blower increased from 6271 to 10270 rev min^{-1} and the air velocity increased from 3 50 to 5 60 ms^{-1} The mean rate of increase in power consumption per unit increase in voltage was 3 70 W As voltage increased from 12 to 24 V, power consumption increased

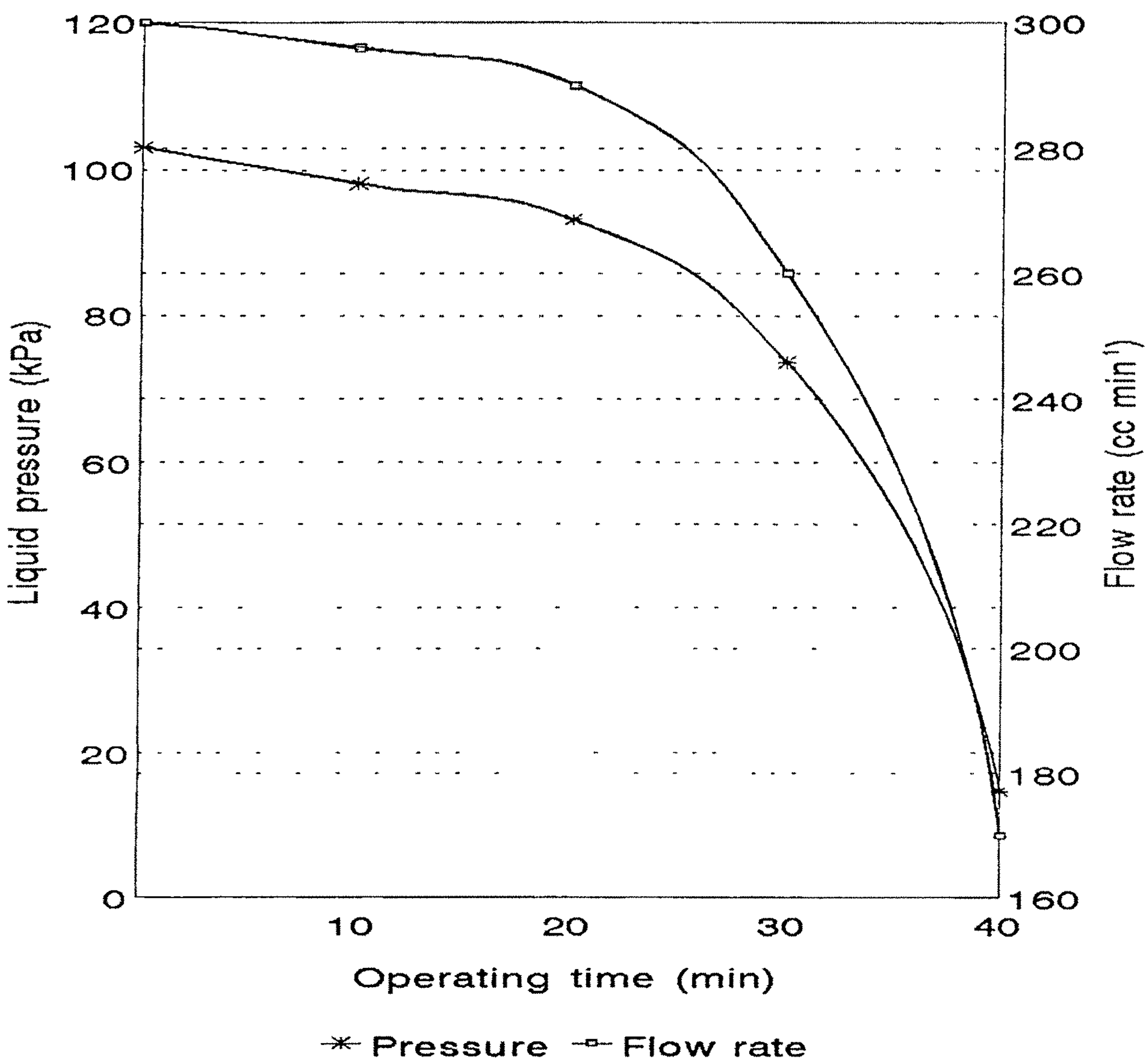


Fig. 4.14 Effect of operating time on liquid pressure and flow rate

Table 4.10. Power consumption of pneumatic spraying system

Sl no	Voltage (V)	Current (A)	Power consumption (W)	Blower speed (rev min^{-1})	Air velocity (ms^{-1})
1	12	1 56	18 72	6271	3 50
2.	13	1 63	21 19	6463	3 70
3	14	1 72	24 08	6870	3 80
4	15	1 81	27 15	7230	4 00
5	16	1 89	30 24	7721	4 10
6	17	1 99	33 83	8065	4 40
7	18	2 06	37 08	8428	4 60
8	19	2 15	40 05	8694	4 80
9	20	2 22	44 40	9013	4 90
10	21	2 36	49 56	9427	5 10
11	22	2 43	53 46	9702	5 30
12	23	2 56	58 88	10012	5 40
13	24	2 63	63 12	10270	5 60

at a constant rate, Fig 4.15 Both the blower speed and air velocity increased linearly as voltage increased from 12 to 24 V, Fig 4 16

b. Effect of air velocity on spray performance

Results of experiments conducted to study the effect of air velocity on spray performance viz , spray distribution pattern and atomization characteristics of the spraying system with 50,65 and 80 cc min^{-1} liquid flow rates are presented and discussed in this section

i. Spray distribution pattern

The results of the spray pattern tests for the spraying system at 5 levels of air velocity (at 5 levels of voltage) for 50,65 and 80 cc min^{-1} liquid flow rate are presented in Tables 4 11, 4 12 and 4 13 respectively The spray pattern curves were observed to flatten as the air velocity increased from 4 1 to 5 6 ms^{-1} for all the three liquid flow rates, Figures 4 17, 4 18 and 4 19

As the air velocity increased, the spray droplets were thrown to greater distances from the point of spray emission and thus the spray pattern curves broaden and flatten As the air velocity increased from 4 1 to 5 6 ms^{-1}, coefficient of variation decreased for all the three liquid flow rates, Fig 20, which indicate that the uniformity of spray volume distribution improved as the air velocity increased

The coefficient of variation of the pneumatic spraying system ranged from 41 52 to 56 33 per cent CV of spray distribution with full fluid flow rate of 80 cc min^{-1} can be

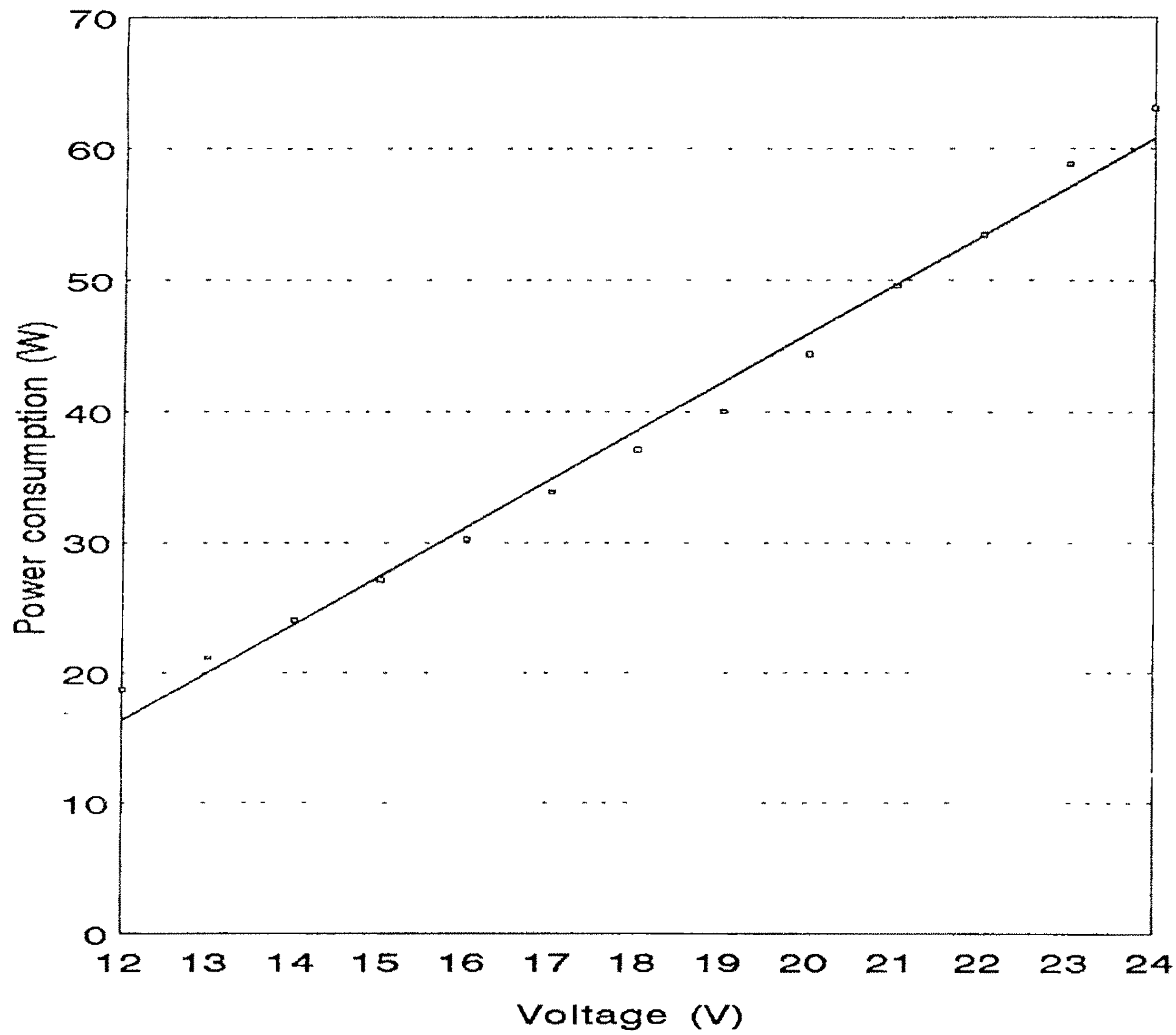


Fig. 4.15 Power consumption for pneumatic spraying system

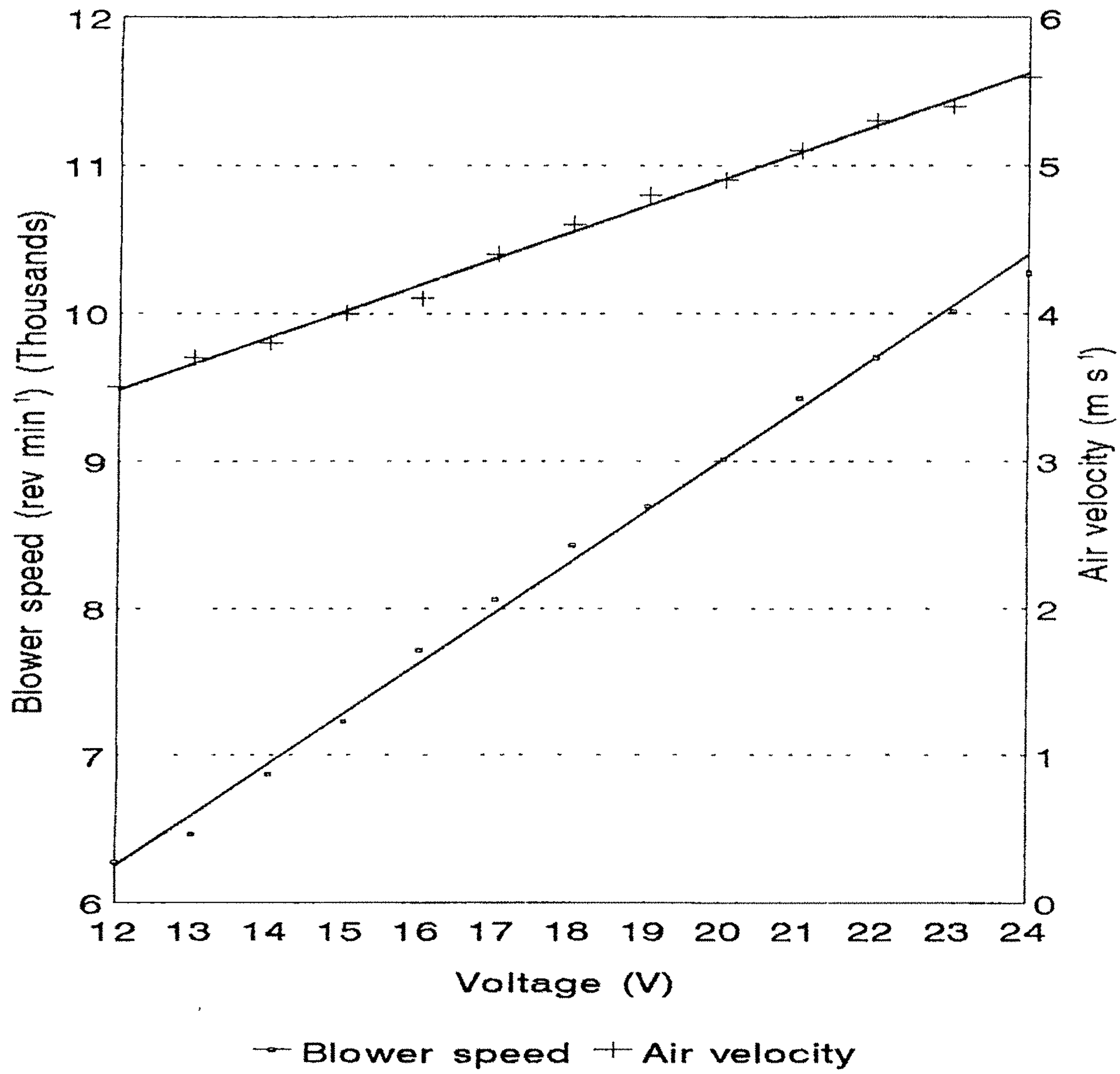


Fig. 4.16 Blower speed at varying voltage

Table 4.11. Effect of air velocity on spray distribution pattern at 50 cc min^{-1} liquid flow rate

Sl no	Horizontal distance from nozzle (mm)	Mean spray volume (cc) Air velocity (ms^{-1})				
		4 1 (16V)	4 6 (18V)	4 9 (20V)	5 3 (22V)	5 6 (24V)
1	360	-	4 5	2 0	-	4 5
2	420	5 5	7 0	5 5	5 0	7 0
3	480	8 0	8 5	7 5	6 0	7 5
4	540	11 0	12 0	10 5	7 5	9 5
5	600	16 0	15 0	11 5	9 5	9 5
6	660	20 0	17 0	13 0	10 5	9 5
7	720	22 0	21 0	19 0	12 5	11 0
8	780	24 5	23 5	22 0	15 5	12 5
9	840	25 5	24 5	23 5	16 5	14 0
10	900	24 0	25 0	21 5	17 5	15 0
11	960	24 0	24 0	20 5	17 5	16 0
12	1020	24 0	23 5	21 5	18 5	18 5
13	1080	20 0	21 5	22 0	18 5	18 0
14	1140	16 5	18 5	18 5	17 0	19 0
15	1200	11 0	16 5	17 0	17 5	20 5
16	1260	5 5	11 5	12 5	13 5	15 5
17	1320	-	8 0	8 0	10 0	14 0
18	1380	-	5 5	5 5	7 0	10 5
19	1440	-	-	-	5 5	5 0
20	1500	-	-	-	-	3 5
	CV (%)	42 51	45 00	43 39	41 52	42 54
Length of spray (mm)		714	792	786	732	672

Table 4.12. Effect of air velocity on spray distribution pattern at 65 cc min^{-1} liquid flow rate

Sl no.	Honzontal distance from nozzle (mm)	Mean spray volume (cc) Air velocity (ms^{-1}) 4 1 (16V)	4 6 (18V)	4 9 (20V)	5 3 (22V)	5 6 (24V)
1	360	-	4 0	4 0	4 0	6 5
2	420	5 0	6 0	5 5	7 0	9 5
3	480	9 0	8 0	7 0	9 0	10 5
4	540	15 0	11 0	10 0	12 0	13 0
5	600	18 5	13 0	11 5	12 5	12 5
6	660	22 0	16 0	15 0	12 0	13 0
7	720	27 0	21 0	20 0	16 5	14 5
8	780	31 0	25 5	25 0	19 5	17 0
9	840	34 5	30 0	29 5	22 5	19 0
10	900	33 5	32 0	32 0	24 5	21 0
11	960	33 0	32 0	33 0	26 5	23 0
12	1020	36 0	34 0	35 0	28 5	26 5
13	1080	33 5	33 5	36 0	30 5	28 0
14	1140	25 0	29 5	30 0	28 5	27 0
15	1200	16 5	29 0	29 0	30 0	28 0
16	1260	8 0	21 0	21.5	25 5	24 0
17	1320	-	13 5	13 0	18 5	17 0
18	1380	-	9 0	8.5	13 5	12 0
19	1440	-	3 0	3 0	8 0	7 0
20	1500	-	-	-	5 5	5 0
	CV (%)	48 76	54 90	56.33	50 84	51 23
Length of spray (mm)		810	846	828	888	942

Table 4.13. Effect of air velocity on spray distribution pattern at 80 cc min^{-1} liquid flow rate

Sl no	Horizontal distance from nozzle (mm)	Mean spray volume (cc) Air velocity (ms^{-1}) 4 1 (16V)	4 6 (18V)	4 9 (20V)	5 3 (22V)	5 6 (24V)
1	360	-	-	-	-	5 5
2	420	-	5 5	5 5	4 0	10 0
3	480	5 5	7 5	6 5	6 0	12 5
4	540	10 5	11 0	9 5	8 5	15 5
5	600	14 0	13 5	11 0	10 0	15 5
6	660	19 5	17 0	15 0	13 0	15 0
7	720	27 0	23 0	20 0	17 5	16 5
8	780	34 5	29 0	25 5	22 5	18 5
9	840	41 5	34 5	31 0	27 0	21 0
10	900	44 5	37 5	34 5	31 0	23 0
11	960	44 0	38 5	36 5	33 0	25 5
12	1020	48 5	42 0	40 0	34 0	30 0
13	1080	44 5	42 0	41 0	38 0	32 5
14	1140	32 0	35 5	36 0	35 5	31 5
15	1200	21 0	33 0	35 5	36 5	34 0
16.	1260	10 0	23 5	26 5	29 5	30 0
17	1320	-	13 0	17 0	21 0	21 5
18	1380	-	7 5	10 0	15 0	17 0
19	1440	-	-	4 0	7 5	9 5
20	1500	-	-	-	-	8 0
	CV (%)	54 13	54 03	53 85	52 37	45 60
Length of spray (mm)		690	840	828	864	996

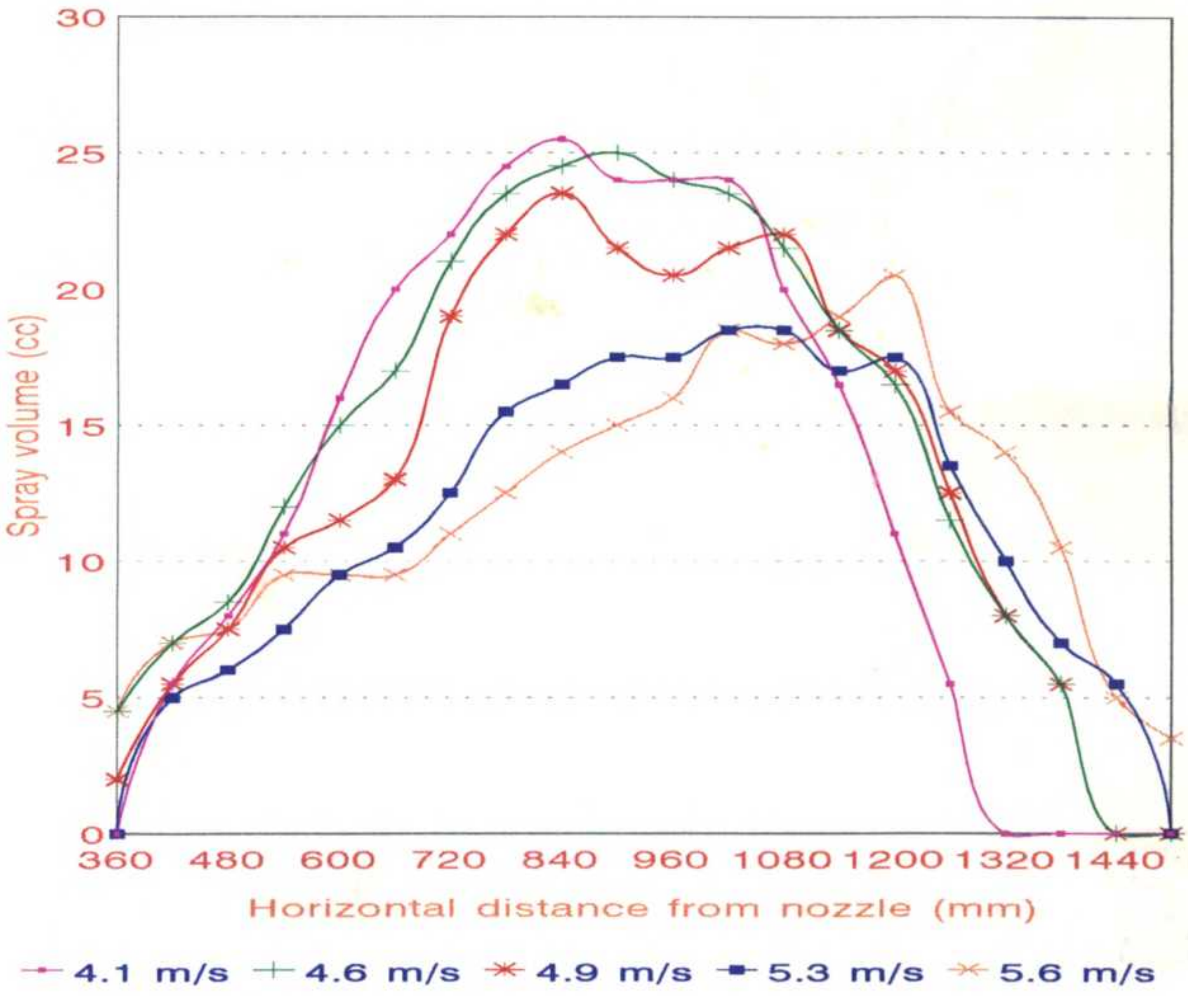


Fig. 4.17 Effect of air velocity on spray distribution pattern at 50 cc min^{-1} liquid flow rate

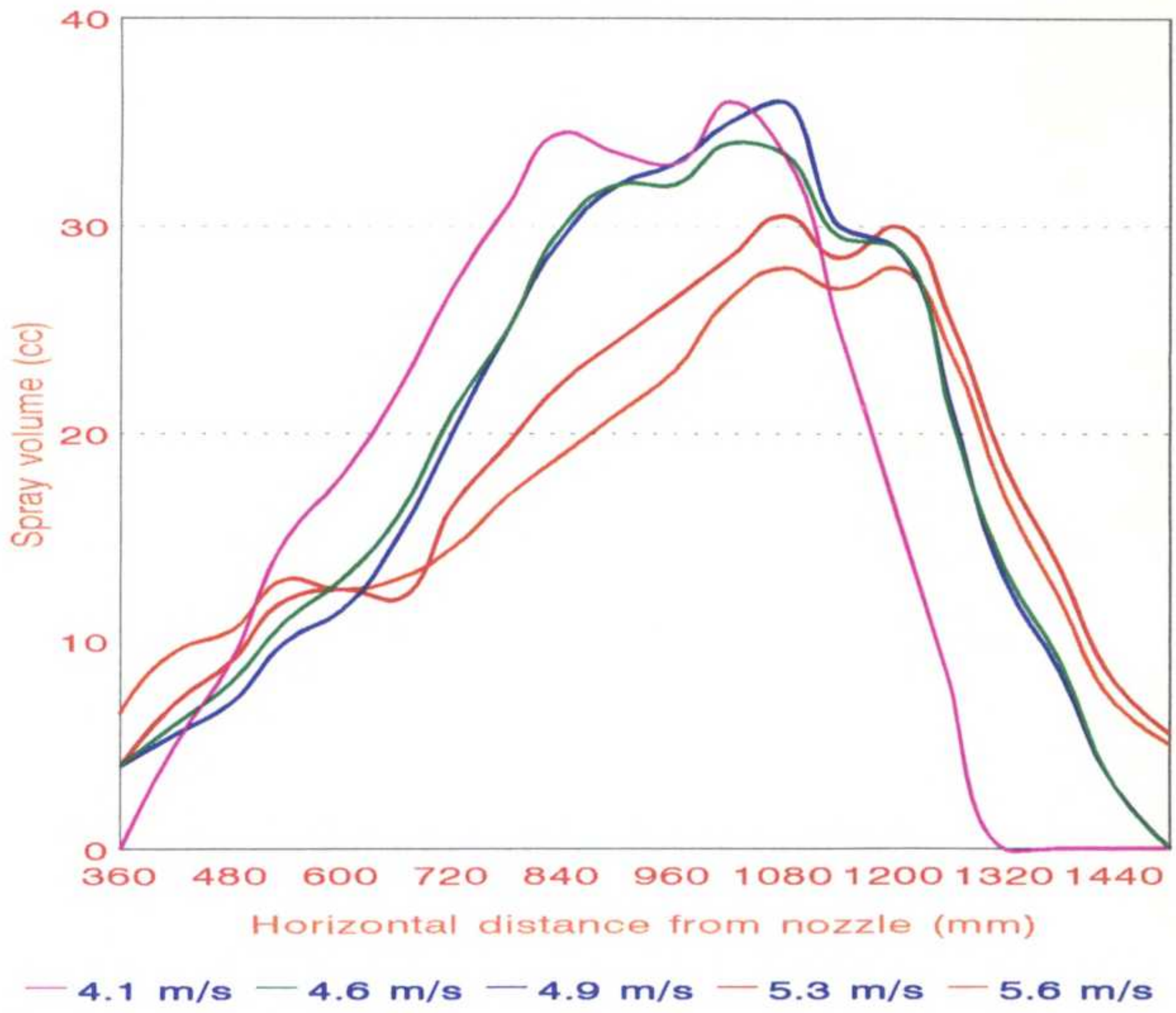


Fig. 4.18 Effect of air velocity on spray distribution pattern at 65 cc min^{-1} liquid flow rate

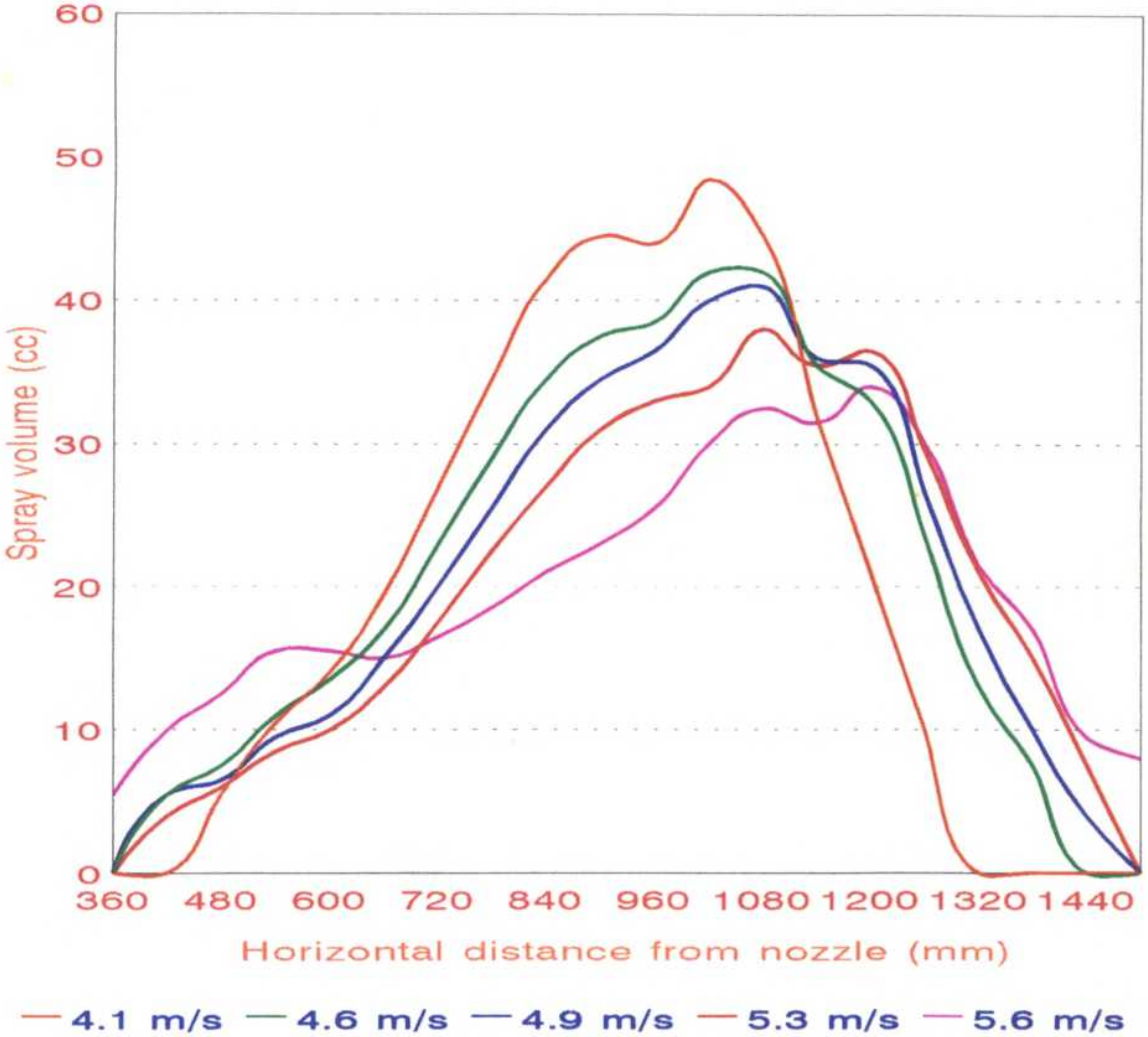
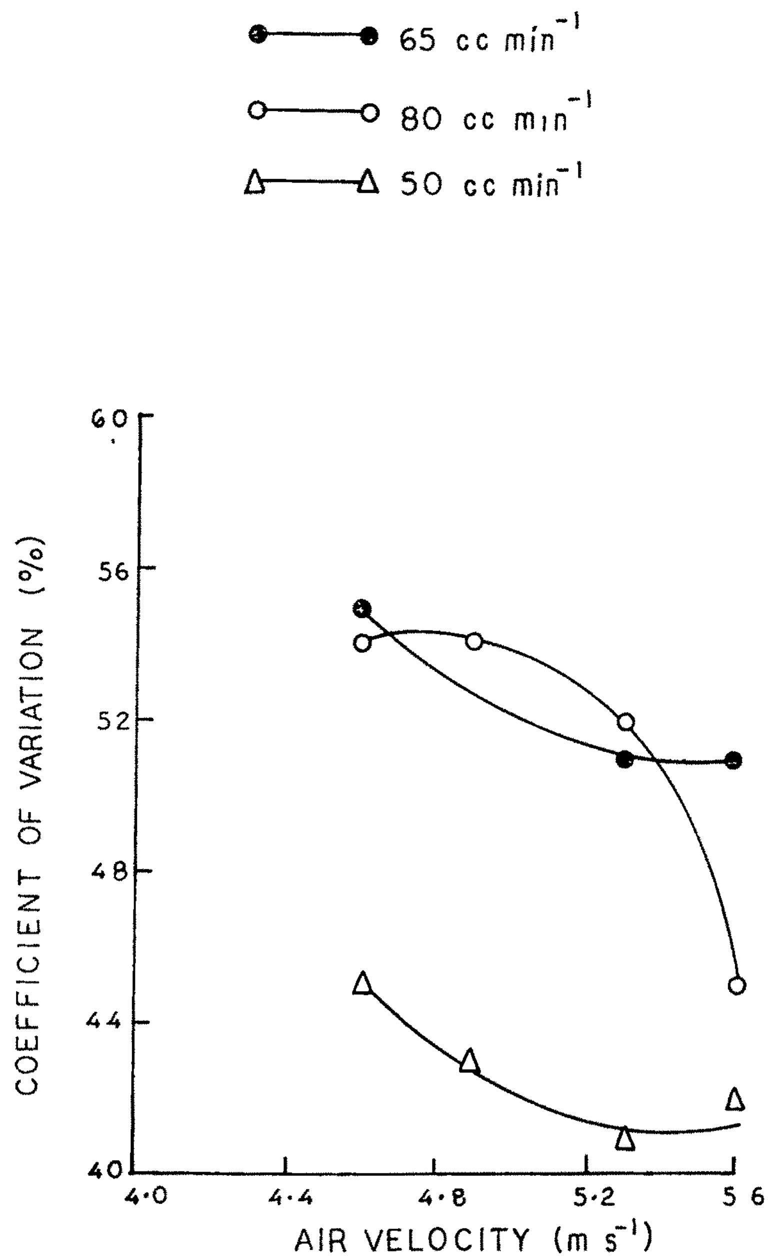


Fig. 4.19 Effect of air velocity on spray distribution pattern at 80 cc min^{-1} liquid flow rate



'IG. 4.20 EFFECT OF AIR VELOCITY ON COEFFICIENT OF VARIATION reduced and the uniformity of spray distribution can be improved by increasing the air velocity beyond 5.6 ms^{-1}

As the air velocity increased from 4 1 to 5 6 ms^{-1}, length of spray decreased in the case of 50 cc min^{-1} liquid flow rate, Fig 4 21 Length of spray increased as the air velocity increased for both 65 and 80 cc min^{-1} liquid flow rates The rate of increase in length of spray was more with 80 cc min^{-1} In the normal operating range of 4 9 to 5 6 ms^{-1} (20 to 24 V range), 80 cc min^{-1} liquid flow rate gave more length of spray when compared to 65 cc min^{-1} Maximum length of spray of 996 mm was obtained at 5 6 ms^{-1} air velocity (24 V) with 80 cc min^{-1} liquid flow rate Therefore among the three liquid flow rates under test, the full fluid flow rate of 80 cc min^{-1} was adopted to study the atomization characteristics of the spraying system

ii. Atomization characteristics

VMD and NMD of spray spectra at 5 levels of air velocity at 400,800 and 1200 mm horizontal distances from the point of spray emission (nozzle) along the axis, 200 mm left and 200 mm right of the nozzle are presented in Tables 4.14,4 15 and 4 16 respectively

VMD of the spray spectra reduced from 249 28 to 212.07 µm as the air velocity increased from 4 1 to 5 6 ms^{-1} at 400 mm distance from the nozzle along the nozzle centre line The VMD reduced from 349 30 to 202 27 µm and from 290 82 to 237 74 µm respectively at 800 and 1200 mm distances from the nozzle Same trend was observed for NMD, Fig 4 22 The droplet size increased from 400 to 800 mm at all

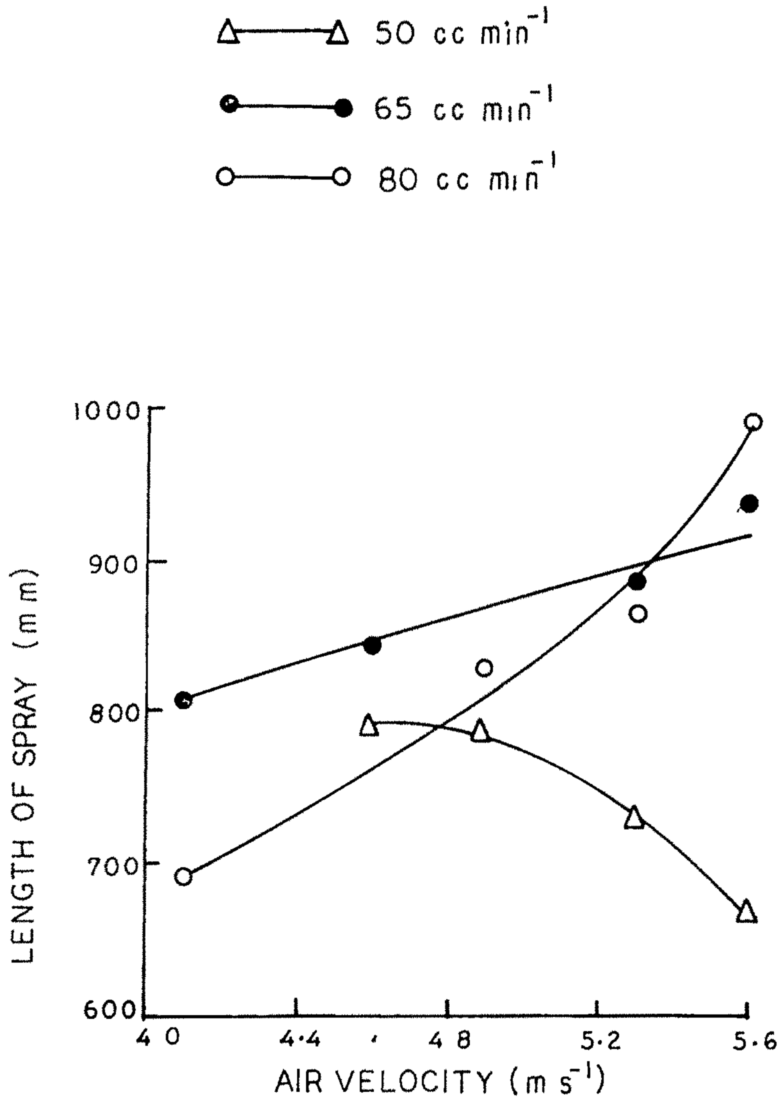


FIG.4.21 EFFECT OF AIR VELOCITY ON LENGTH OF SPRAY

Table 4.14. Effect of air velocity on atomization characteristics along the axis of the nozzle

Ambient temperature 30 5°C (db)
Relative humidity 58 5 per cent

Sl no	Air velocity (ms^{-1})	Horizontal distance from nozzle (mm)								
		400			800			1200		
		VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD
1	4 1	249 28	205 59	1 213	349 30	273 58	1 277	290 82	241 15	1 206
2	4 6	185 63	160 85	1 154	239 25	193 11	1 239	241 37	198 00	1 219
3	4 9	226 73	203 08	1 117	257 61	190 06	1 355	245 59	185 92	1 321
4	5 3	207 42	165 65	1 252	234 22	187 09	1 252	205 02	167 51	1 224
5	5 6	212 07	177 18	1 197	202 27	164 71	1 228	237 74	193 10	1 231

Table 4.15. Effect of air velocity on atomization characteristics at 200 mm left to the nozzle

Ambient temperature : 30 5°C (db)

Relative humidity : 58 5 per cent

Sl no	Air velocity (ms^{-1})	Horizontal distance from nozzle (mm)								
		400			800			1200		
		VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD
1	4 1	208 14	153 23	1 358	348 21	305 72	1 139	436 87	388 54	1 130
2	4 6	232 12	212 03	1 095	373 07	324 87	1 148	300 34	179 93	1 670
3	4 9	220 89	195 77	1 128	322 81	297 69	1 084	384 64	237 62	1 619
4	5 3	195 28	149 61	1 305	409 53	326 32	1 255	326 28	270 15	1 208
5	5 6	246 58	200 78	1 228	361 14	263 44	1 371	438 68	257 32	1 705

Table 4.16. Effect of air velocity on atomization characteristics at 200 mm right to the nozzle

Ambient temperature 30 5°C (db)

Relative humidity 58 5 per cent

Sl no	Air velocity (ms^{-1})	Horizontal distance from nozzle (mm)								
		400			800			1200		
		VMD (μm)	NMD (μm)	VMD/NMD	VMD (μm)	NMD (μm)	VMD/NMD	VMD (μm)	NMD (μm)	VMD/NMD
1	4 1	305 18	255 17	1 196	394 35	367 49	1 074	150 14	110 23	1 362
2	4 6	184 03	141 24	1 303	294 26	237 77	1 230	147 64	131 32	1 124
3	4 9	291 13	198 81	1 464	307 18	203 92	1 506	167 72	129 51	1 295
4	5 3	259 33	233 87	1 109	289 75	260 98	1 110	175 82	119 25	1 474
5	5 6	175 19	139 08	1 260	189 53	139 96	1 354	190 09	146 76	1 295

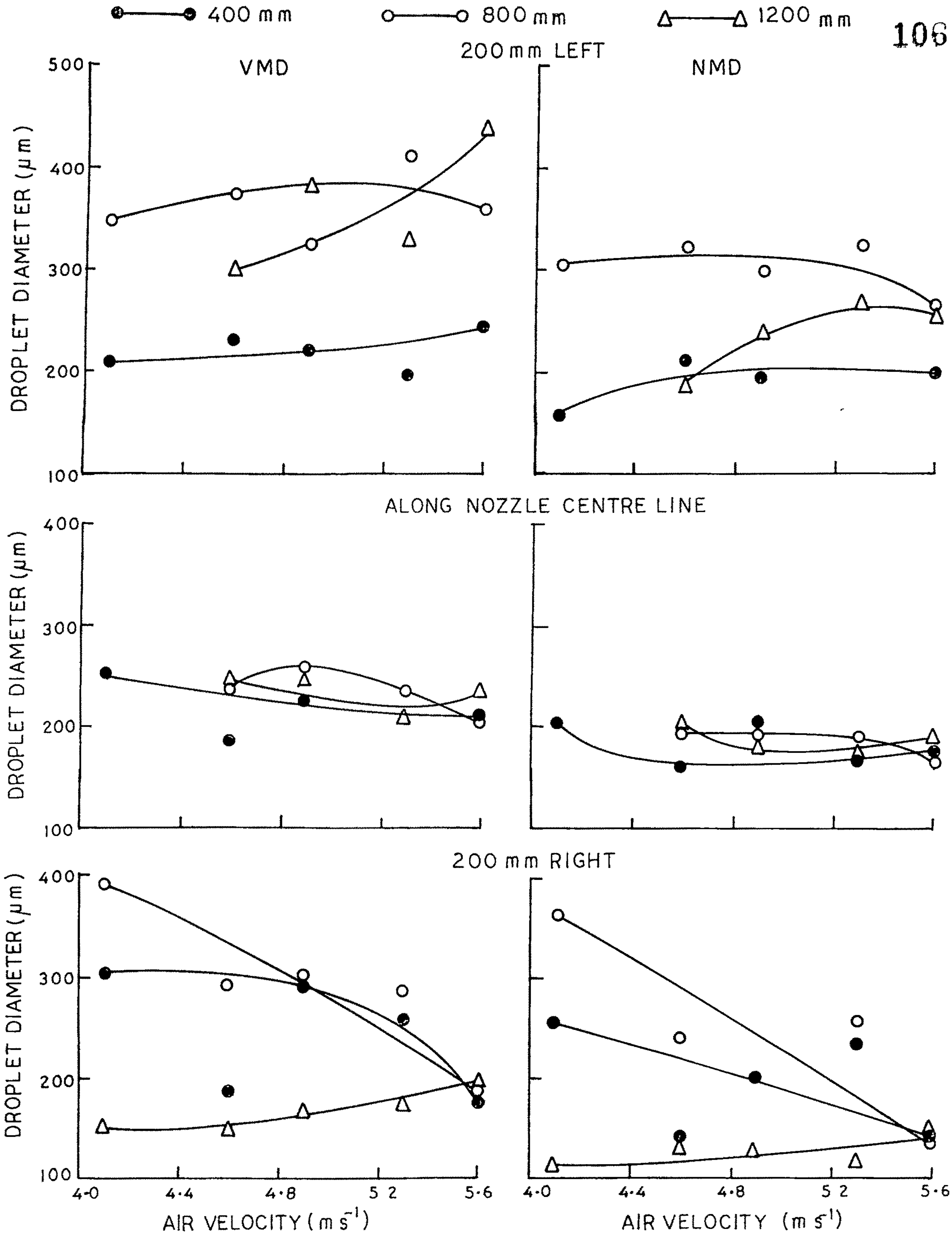


FIG.4.22 EFFECT OF AIR VELOCITY ON ATOMIZATION CHARACTERISTICS

the levels of air velocity As the distance from the nozzle increased from 800 to 1200 mm, droplet size decreased.

In the case of 1 25 kW engine powered knapsack sprayer at an air flow rate of 6 98 m^3 min^{-1} and at any given liquid flow rate, an increase in the distance from the point of spray emission had an increasing effect on droplet size upto 51 23 ms^{-1} air velocity Beyond this air velocity, droplet size decreased (Tajuddin *et al*, 1978) But in the case of battery powered (63 W) pneumatic spraying system, the droplet size increased as the distance from the nozzle increased from 400 to 1200 mm in the 5 1 to 5 6 ms^{-1} range of air velocity Below 5 1 ms^{-1} air velocity, droplet size increased as the distance increased from 400 to 800 mm and the droplet size decreased as the distance increased from 800 to 1200 mm along the axis of the nozzle

Uniformity of droplet size distribution, as envisaged by the VMD NMD ratio, varied from 1 12 to 1 21 at 400 mm distance, from 1 23 to 1 36 at 800 distance and from 1 21 to 1 32 at 1200 mm distance along the axis of the nozzle The above data reveal that the uniformity of droplet distribution becomes poorer as the distance from the nozzle increased.

Lesser VMD NMD ratio was obtained for the spray spectra at 400 and 800 mm distances when compared to 1200 mm distance from the nozzle, Fig 4 23. The VMD NMD ratio varied from 1 12 to 1 36 along the axis of the nozzle, from 1 10 to 1 71 along the lateral line 200 mm left to the nozzle and from 1 11 to 1 51 along the lateral line 200 mm right to the nozzle This shows that better uniformity of droplet size

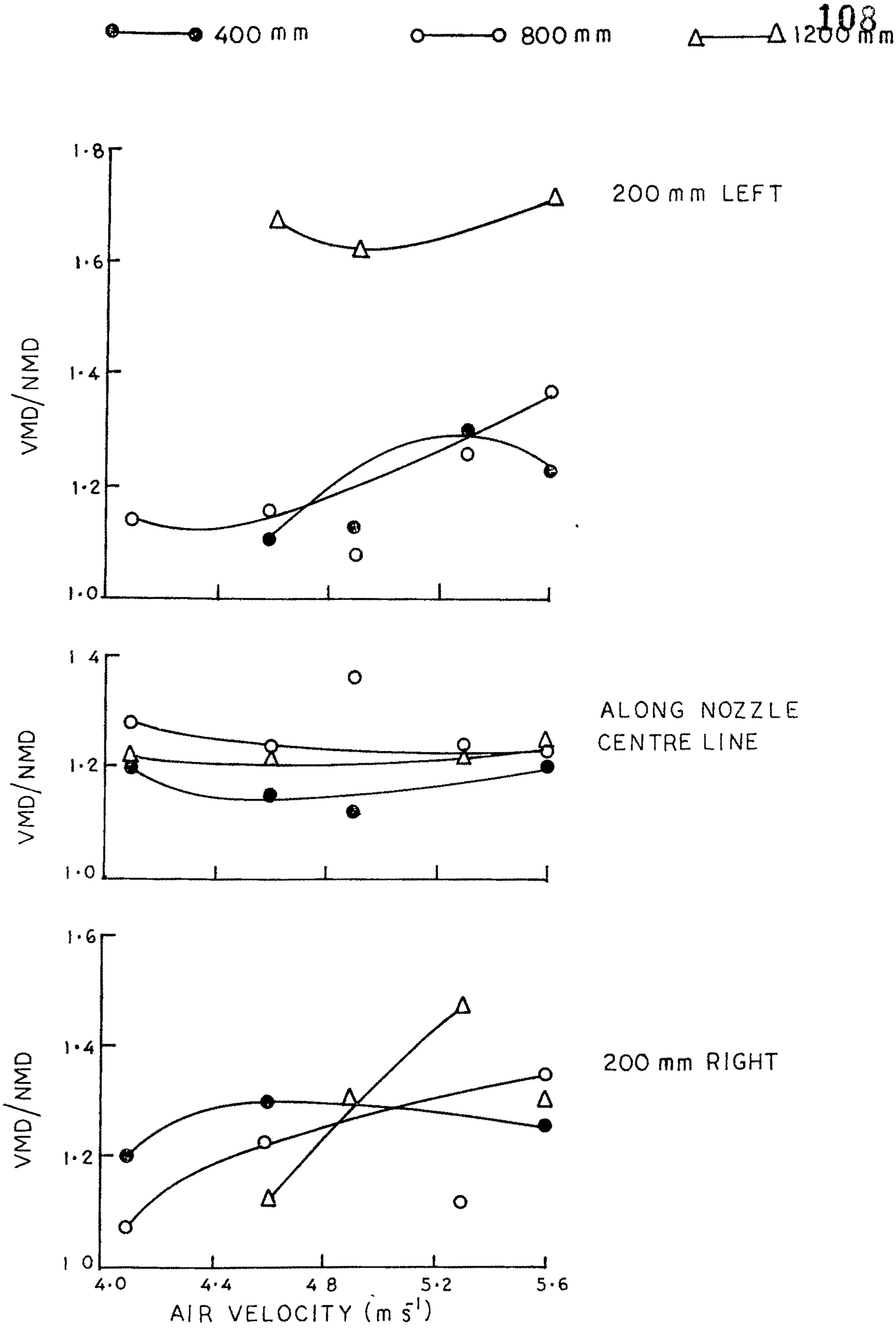


FIG.4.23 EFFECT OF AIR VELOCITY ON VMD/NMD RATIO

distribution was obtained along the axis of the nozzle than towards the left and right sides of the nozzle The VMD:NMD ratios at 400 and 800 mm distances from the nozzle were close to each other than at 1200 mm distance

c. Energy release pattern of battery

Battery voltage, amperage and power consumption of the DC motor, rotational speed of the blower of the pneumatic spraying system when operated continuously with battery are presented in Table 4 17

Table 4.17. Energy release pattern of battery for pneumatic spraying system

Sl no.	Operating time (min)	Battery voltage (V)	Current (A)	Power consumption (W)	Blower speed (rev min^{-1})
1	0	23 8	2 80	66 64	11543
2	10	23 1	2 77	64 00	11453
3	20	22 8	2 65	61 42	11138
4	30	22 6	2 60	58 76	10835
5	40	22.2	2 57	57 05	9956
6	50	21 8	2.52	54 94	8073
7	60	21 4	2 48	53 07	5537
8	70	20 7	2 42	50 09	4432
9	80	18 5	2 32	42.92	3814
10	90	14 0	1 93	27 02	2064

Battery voltage reduced at a constant rate upto 60 min operation, Fig 4 24 Power consumption of the DC motor also reduced linearly from 0 to 60 min of operation Beyond 60 min of operation, both battery voltage and power consumption curves drooped down drastically This indicates that the effective service time of the battery per cycle was 60 min In the time interval of 0 to 60 min, voltage reduced from 23 8 to 20 7 V and power consumption reduced from 66 64 to 50 09 W

Rotational speed of the blower reduced from 11500 to 5500 rev min^{-1} in the 0 to 60 min range of operation, Fig 4 25 Beyond 60 min of operation, the rate of decrease in blower speed reduced

4.3.3. Battery powered centrifugal spraying system

Experimental data collected to study the effect of spinning disc speed on spray distribution pattern and atomization characteristics of the spraying system are presented and discussed in this section Power consumption and energy release pattern of battery for the system have also been presented and discussed

a. Effect of design and speed of spinning disc on spray performance

Results of the experiments conducted to study the effect of inclined grooves and straight grooves in the periphery of spinning disc on spray performance viz , spray distribution pattern and atomization characteristics of the spraying system at different levels of spinning disc speed are presented and discussed under this section

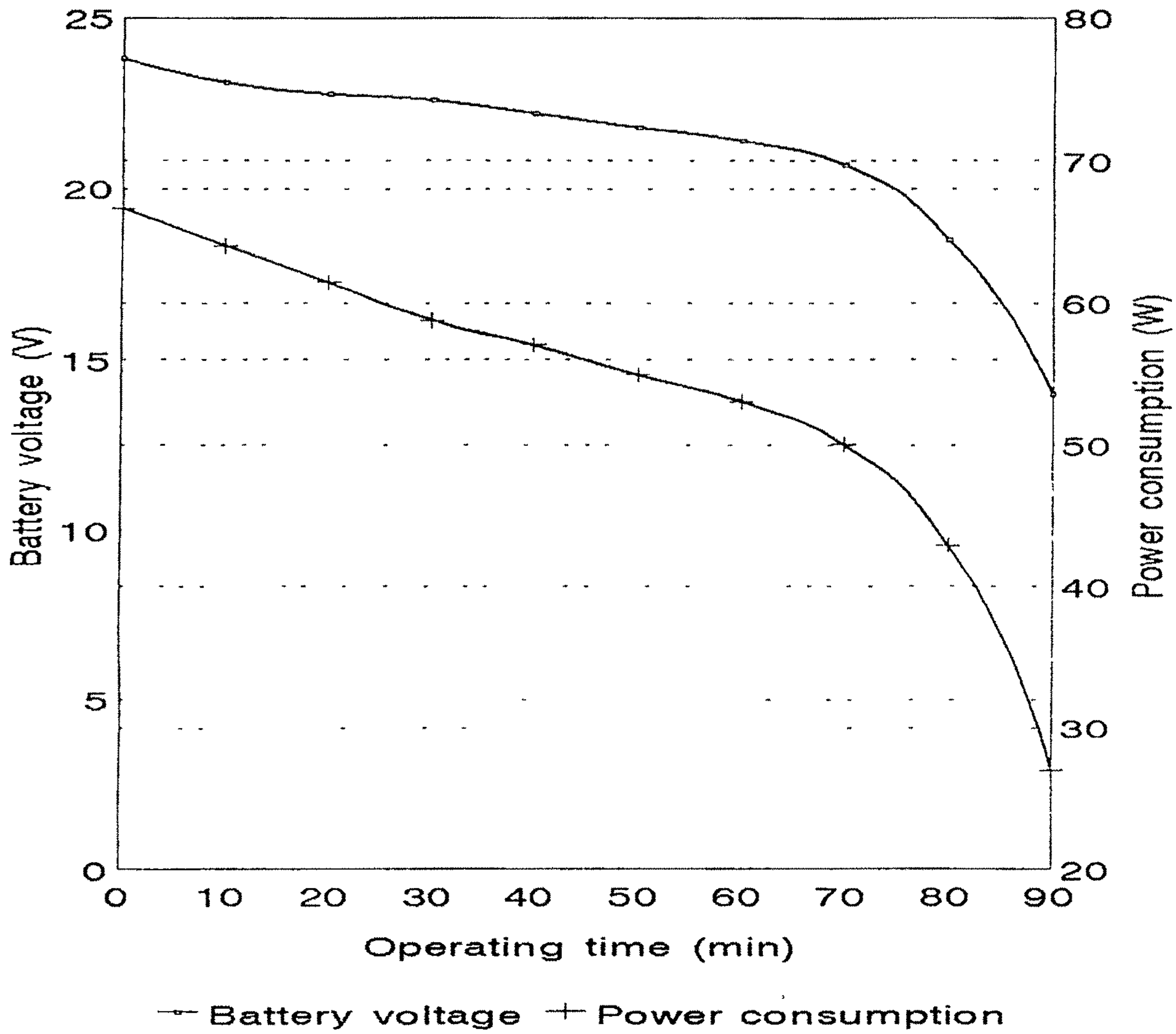


Fig. 4.24 Energy release pattern of battery for pneumatic spraying system

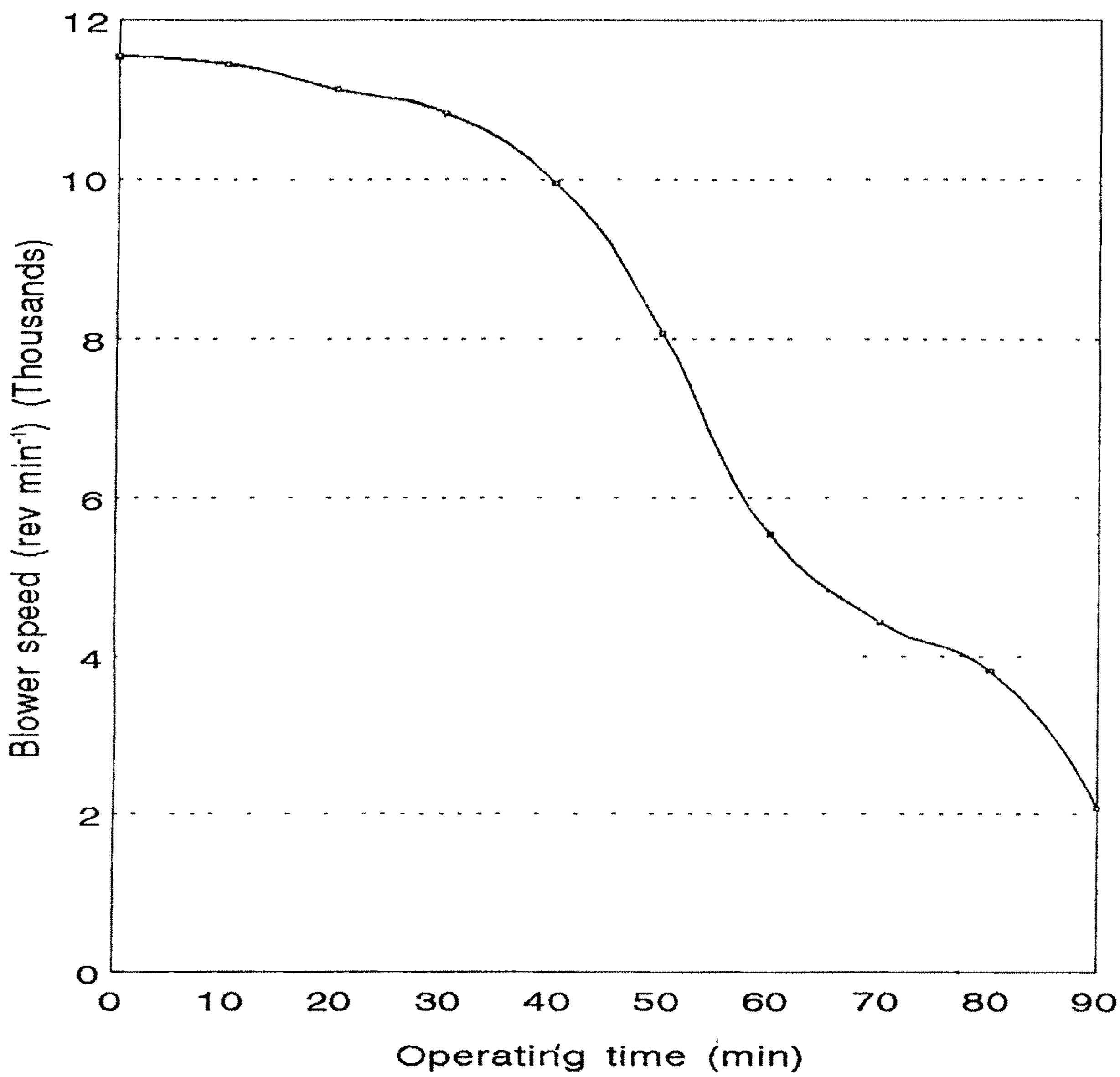


Fig. 4.25 Effect of operating time on blower speed

i. Spray distribution pattern

Spray pattern test results of the spraying system with inclined grooved and straight grooved spinning discs at 5 levels of spinning disc speed (at 5 levels of voltage) and at 75 and 150 cc min^{-1} liquid flow rates are presented in Tables 4 18, 4 19, 4 20 and 4 21

At 75 cc min^{-1} flow rate, the spray volume increased throughout the length of spray swath as the rotational speed of the inclined grooved spinning disc increased from 3400 to 4120 rev min^{-1}, Fig 4 26 Similar trend was observed for the straight grooved spinning disc and for 150 cc min^{-1} flow rate, Figures 4 27, 4 28 and 4 29

The spray distribution pattern curves of the straight grooved spinning disc with 75 cc min^{-1} flow rate were close to each other at all levels of spinning disc speed, when compared to the corresponding spray pattern curves of the inclined grooved spinning disc The spray pattern curves of the inclined grooved disc with 150 cc min^{-1} flow rate had more deviations from the mean values when compared to the corresponding spray pattern curves of the straight grooved spinning disc This might be due to the streamlined distribution paths of the liquid ligaments leaving the spinning disc periphery in the case of straight grooved disc. The smooth and streamlined trajectories of liquid ligaments might be disturbed by the inclined grooves and hence the deviations were more in the spray pattern of inclined grooved disc

The effect of inclined and straight grooves on the spinning disc periphery on CV at 75 and 150 cc min^{-1} flow rates is illustrated in Fig 4 30 At 75 cc min^{-1} flow rate, as

Table 4.18 Effect of speed of inclined grooved spinning disc on spray distribution pattern at 75 cc min^{-1} flow rate

Sl no	Honzontal distance from spinning disc centre (mm)	Mean spray volume (cc) Spinning disc speed (rev min^{-1}) 3405 (10V)	3767 (11V)	4122 (12V)
1	-780	5 5	9 5	10 5
2	-720	4 0	9 5	11 5
3	-660	5 5	9 0	11 5
4	-600	5 0	8 5	12 0
5	-540	5 0	8 5	12 5
6	-480	5 5	9 5	13 5
7	-420	6 0	10 0	14 0
8	-360	6 5	10 0	13 5
9	-300	6 5	10 0	13 0
10	-240	5 0	9 0	11 5
11	-180	5 5	9 0	11 0
12	-120	5 5	7 5	9 5
13.	-60	5 0	7 0	8 0
14	0	5 0	6 5	8 0
15	60	5 0	7 0	8 0
16	120	5 0	7 0	8 5
17	180	5 0	7 0	9 0
18	240	5 0	7 0	9 0
19	300	5 0	6 5	9 0
20	360	5 0	6 5	8 0
21	420	4 0	5 5	8 0
22	480	4.0	5 0	7 5
23	540	4 0	5 0	7 5
24	600	4 0	5 0	8 0
25	660	3 5	4 5	5 5
26	720	2 5	4 0	4 5
27	780	2 0	3 5	4 0
	CV (%)	13 49	22 05	22 44
	Power (W)	7 50	9 32	11 45

Table 4.19 Effect of speed of straight grooved spinning disc on spray distribution pattern at 75 cc min^{-1} flow rate

Sl no	Horizontal distance from spinning disc centre (mm)	Mean spray volume (cc) Spinning disc speed (rev min^{-1}) 3405 (10V)	3767 (11V)	4122 (12V)
1	-780	5 0	6 5	8 0
2	-720	5 5	9 0	7 5
3	-660	5 5	8 0	7 5
4	-600	5 0	7 0	7 0
5	-540	4 5	6 0	6 0
6	-480	4 5	6 0	6 0
7	-420	4 5	7 0	6 0
8	-360	4 5	7 0	6 5
9	-300	4 5	7 0	6 5
10	-240	4 0	7 0	6 5
11	-180	4 0	6 0	5 5
12	-120	4 0	6 0	5 0
13	-60	4 0	6 0	5 5
14	0	3 5	6 0	5 0
15	60	3 5	7 0	5 0
16	120	3 5	7 0	6 0
17	180	4 0	7 0	6 0
18	240	4 0	7 0	6 0
19	300	4 0	7 0	6 0
20	360	4 0	7 0	5 0
21	420	4 0	7 0	6 5
22	480	4 0	9 0	6 5
23	540	5 0	11 0	8 5
24	600	5 5	13 0	10 0
25	660	6 0	12 0	11 0
26	720	5 0	10 0	8 5
27	780	4 0	8 0	6 0
	CV (%)	26 12	24 69	22 06
	Power (W)	5 23	7 15	9 80

Table 4.20 Effect of speed of inclined grooved spinning disc on spray distribution pattern at 150 cc min^{-1} flow rate

Sl no	Horizontal distance from spinning disc centre (mm)	Mean spray volume (cc)				
		Spinning disc speed (rev min^{-1})				
		2592 (8V)	3092 (9V)	3395 (10V)	3690 (11V)	4085 (12V)
1	-780	8 0	11 0	10 5	18 5	22 0
2	-720	9 0	12 5	11 0	19 0	23 0
3	-660	14 0	14 5	16 0	20 0	24 0
4	-600	17 0	15 0	16 0	21 0	26 0
5	-540	17 0	16 0	16 5	21 0	27 0
6	-480	17 0	16 0	15 5	22 5	28 5
7	-420	16 0	15 5	15 5	24 0	28 0
8	-360	13 5	14 5	13 5	22 0	25 5
9	-300	12 0	13 5	13 0	20 5	25 5
10	-240	10 0	11 0	10 5	19 0	22 5
11	-180	9 0	13 0	11 5	18 5	21 5
12	-120	8 0	11 0	10 0	13 0	17 0
13	-60	9 5	9 5	9 5	16 5	18 5
14	0	8 0	10 5	10 0	17 0	19 5
15	60	11 5	10 0	10 5	17 0	21 0
16	120	14 0	12 5	11 0	17 5	21 0
17	180	18 5	13 0	14 5	19 0	22 5
18	240	20 5	12 0	12 5	19 0	23 0
19	300	23 5	13 0	13 5	19 0	22 5
20	360	29 0	13 0	11 5	17 5	22 5
21	420	29 5	12 5	10 0	16 0	20 5
22	480	29 0	12 0	9 5	14 5	17 0
23	540	29 0	15 0	12 0	13 0	14 5
24	600	7 5	11 5	12 5	13 0	15 0
25	660	3 0	7 0	10 5	12 5	13 5
26	720	3 0	5 0	9 0	11 5	13 0
27	780	2 0	4 0	8 0	10 0	12 0
	CV (%)	20.55	17 37	18 44	15 87	16 36
	Power (W)	5 84	6 75	8 70	9 13	10 80

Table 4.21 Effect of speed of straight grooved spinning disc on spray distribution pattern at 150 cc min^{-1} flow rate

Sl no.	Horizontal distance from spinning disc centre (mm)	Mean spray volume (cc)				
		Spinning disc speed (rev min^{-1})				
		2592 (8V)	3092 (9V)	3395 (10V)	3690 (11V)	4085 (12V)
1	-780	8 5	11 5	15 0	20 0	20 5
2	-720	10 5	14 0	16 0	23 5	22 0
3	-660	12 0	16 0	16 0	26 0	24 0
4	-600	14 5	17 0	17 0	26 5	25 0
5	-540	16 5	19 5	17 0	26 5	24 5
6	-480	17 5	14 0	17 0	26 5	24 5
7	-420	16 0	18 0	17 0	25 0	25 0
8	-360	16 0	18 0	18 0	24 5	25 5
9	-300	13 5	15 5	16 5	22 0	24 5
10	-240	12 5	14 0	16 0	20 0	23 5
11	-180	10 5	12 5	13 5	18 5	22 0
12	-120	8 0	9 5	11 5	14 5	17 0
13	-60	9 0	10 5	11 0	17 0	20 0
14	0	8 5	10 5	10 5	16 0	18 0
15	60	10 0	10 5	11 5	17 5	19 0
16	120	11 0	11 5	12 5	18 0	20 0
17	180	12 0	13 5	14 5	18 5	20 0
18	240	12 5	14 5	14 5	18 0	20 5
19	300	13 5	14 5	15 0	17 0	14 5
20	360	15 0	14 5	14 5	18 0	21 0
21	420	17 0	15 0	14 5	19 0	20 0
22.	480	17 0	14 5	14 0	19 0	19 0
23	540	19 0	15 5	14 5	19 5	18 5
24	600	20 0	17 0	16 5	21 5	18 5
25	660	12 5	19 0	19 0	24 5	20 5
26	720	7 5	14 5	17 5	25 5	22 5
27	780	3 5	18 5	15 0	24 0	23 0
	CV (%)	26 29	20 64	14 65	18 29	11 65
	Power (W)	4 96	5 85	7 40	8 45	9 84

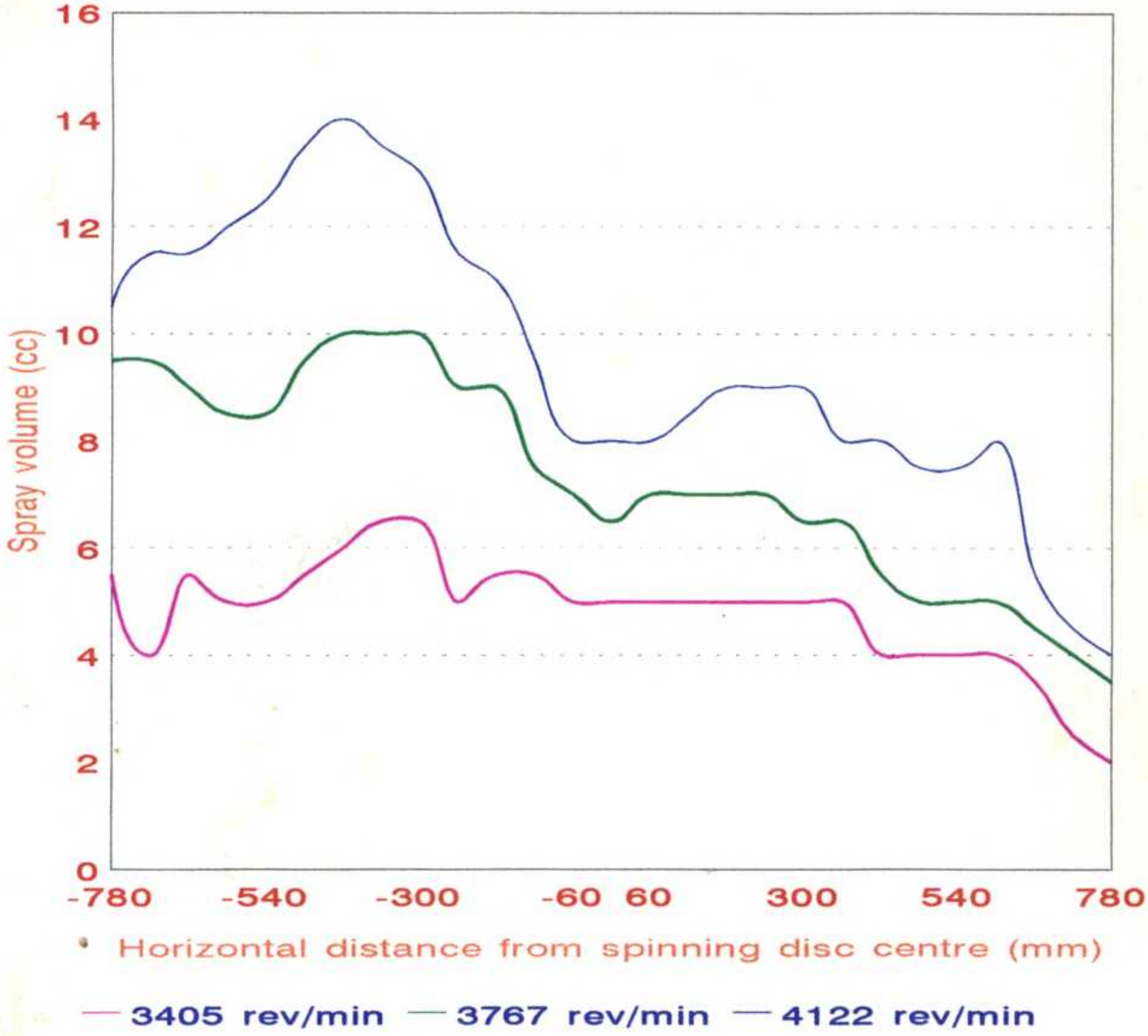


Fig. 4.26 Effect of speed of inclined grooved spinning disc on spray distribution pattern at 75 cc min^{-1} flow rate

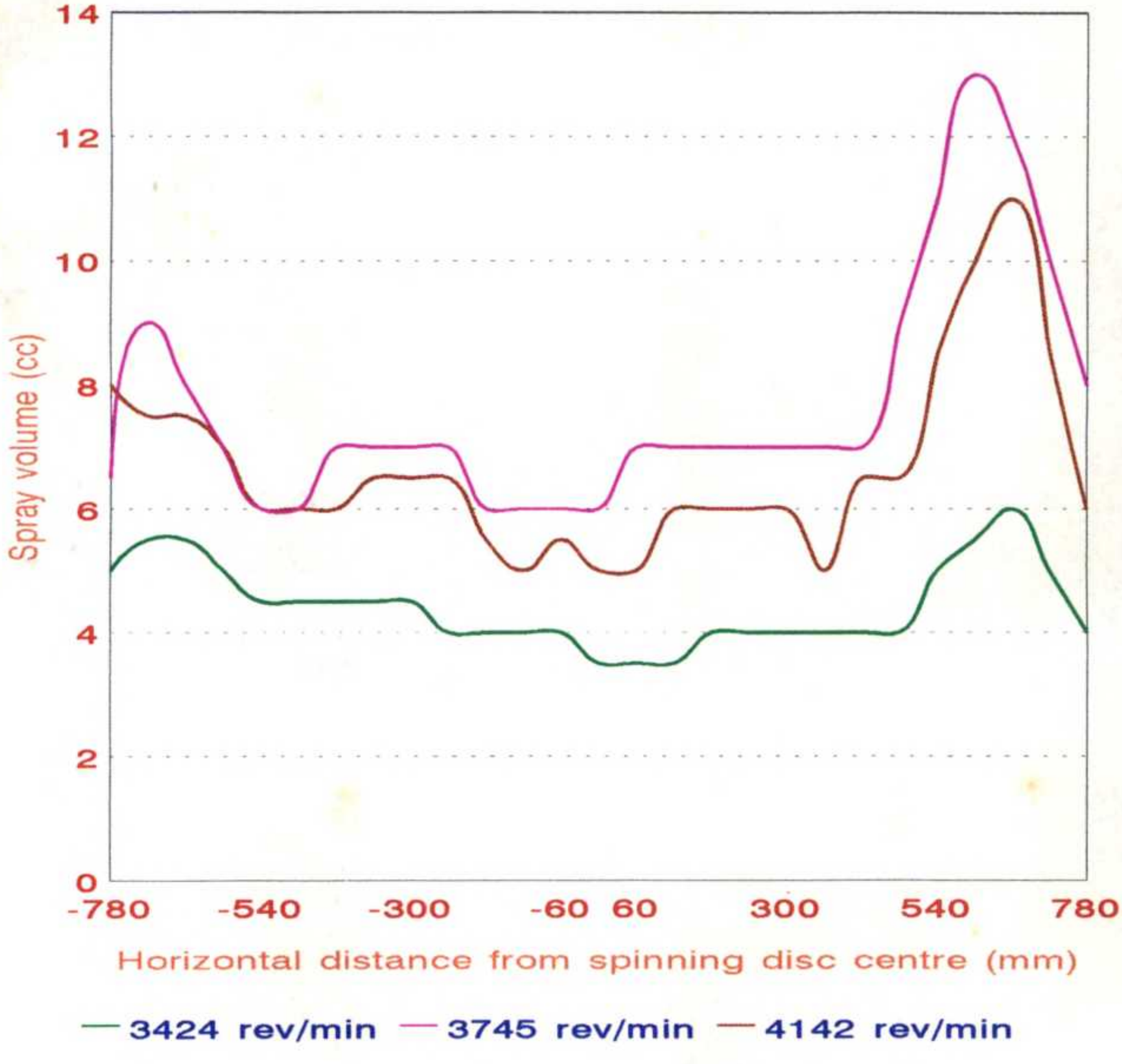


Fig. 4.27 Effect of speed of straight grooved spinning disc on spray distribution pattern at 75 cc min^{-1} flow rate

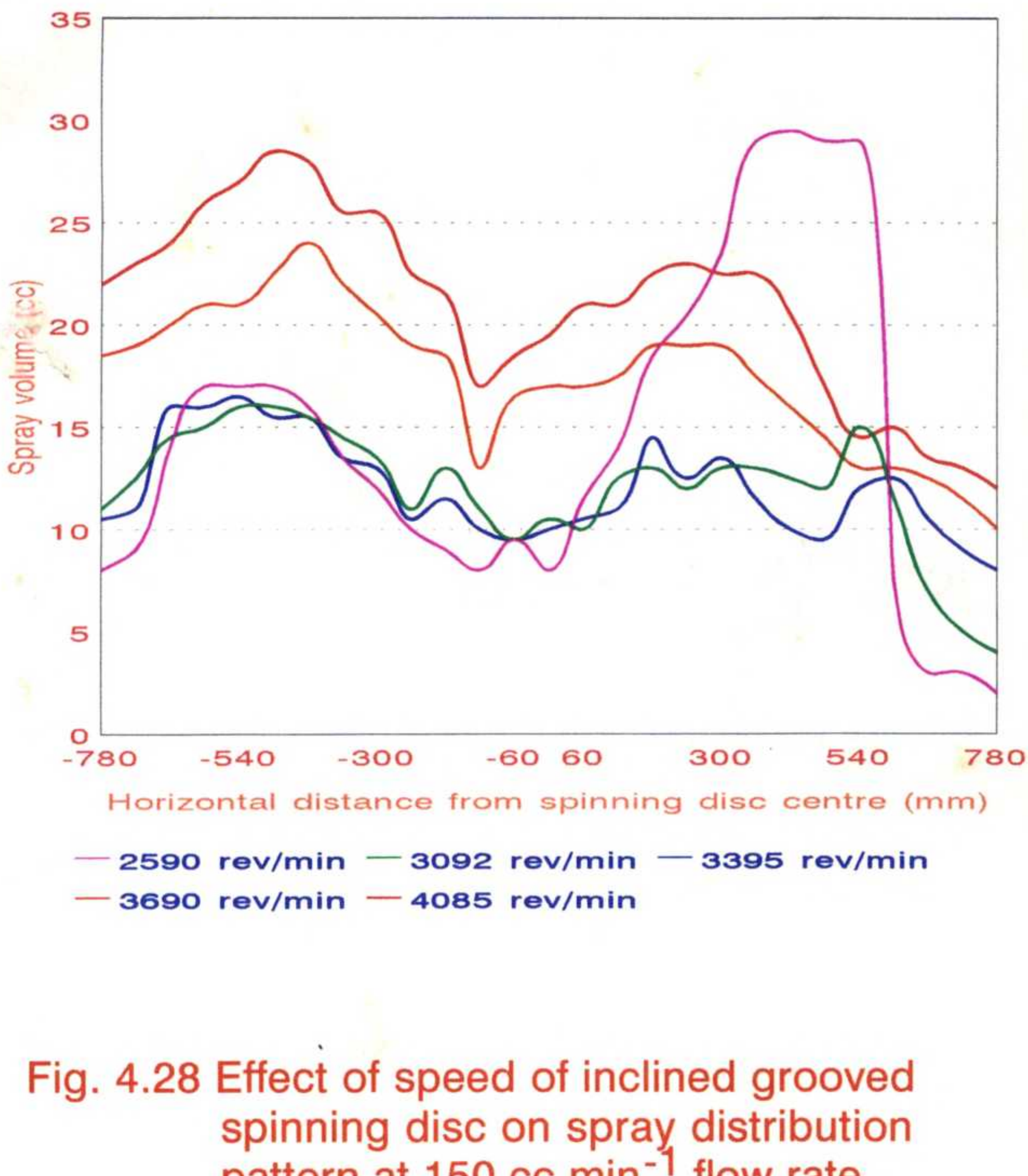


Fig. 4.28 Effect of speed of inclined grooved spinning disc on spray distribution pattern at 150 cc min^{-1} flow rate

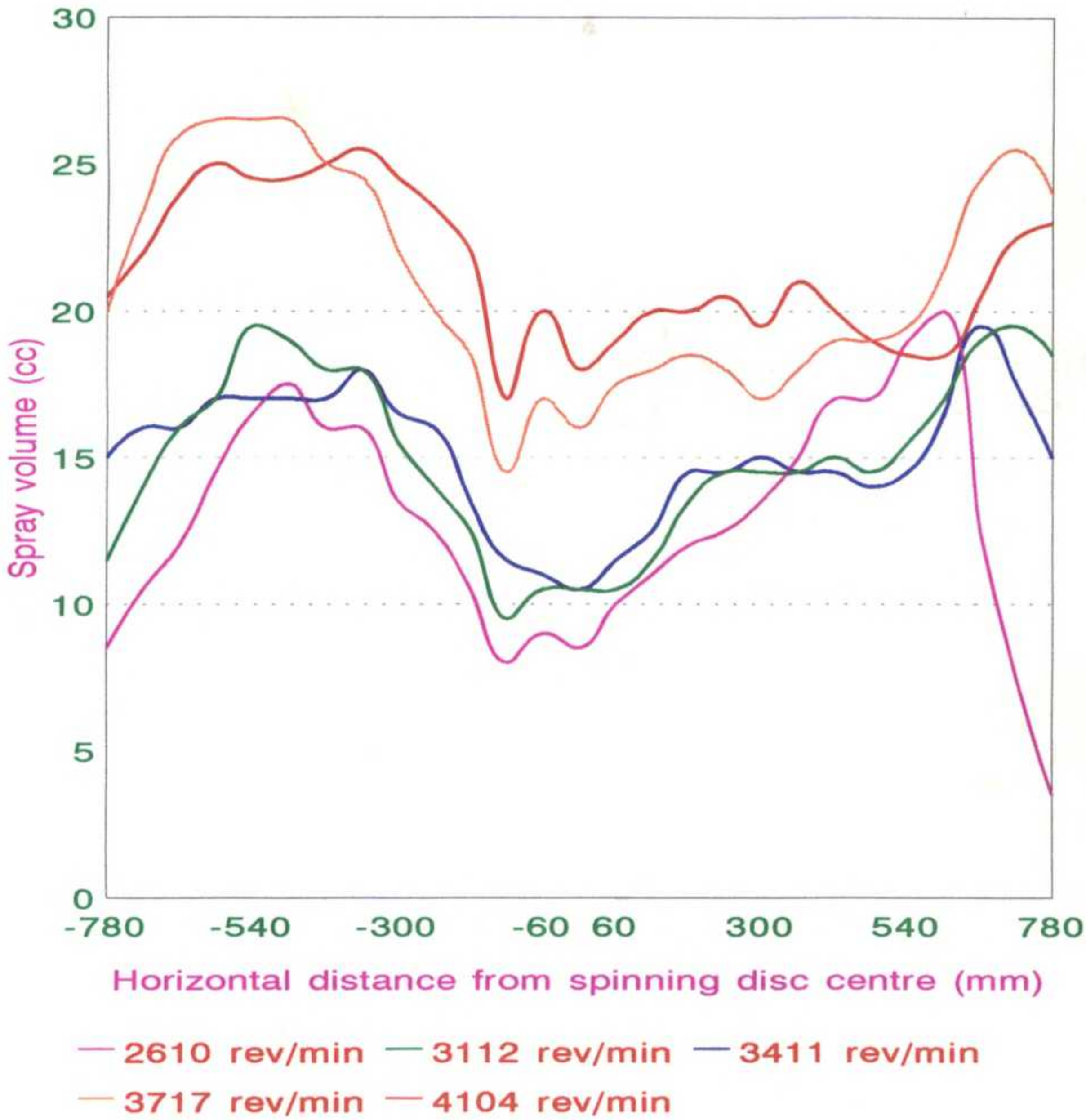


Fig. 4.29 Effect of speed of straight grooved spinning disc on spray distribution pattern at 150 cc min^{-1} flow rate

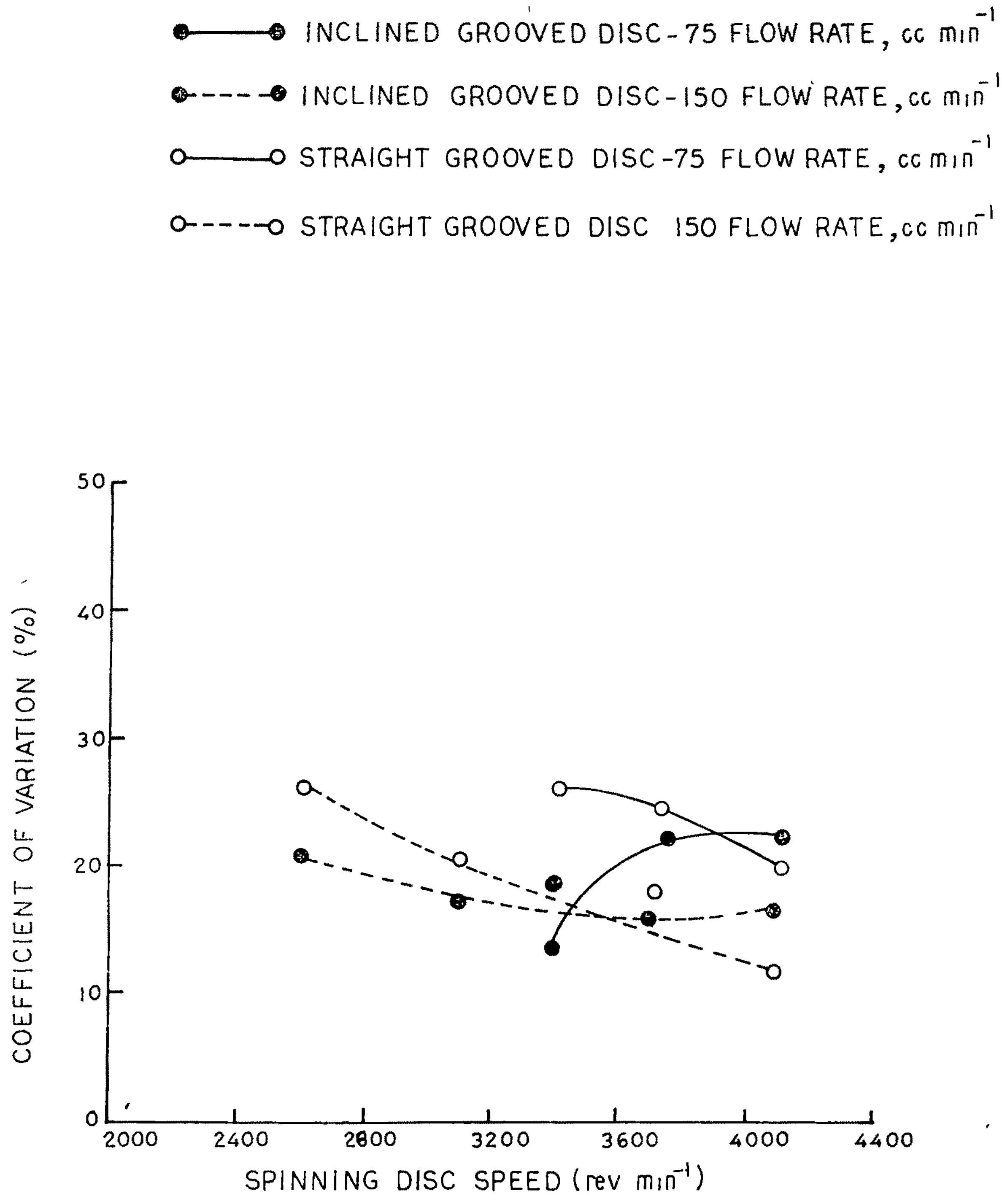


FIG.4.30 EFFECT OF SPINNING DISC SPEED ON COEFFICIENT OF VARIATION

the spinning disc speed increased CV increased for the inclined grooved disc and CV decreased for the straight grooved disc At 150 cc min^{-1} flow rate in the normal operating range of 3600 to 4100 rev min^{-1} spinning disc speed (10 to 12 V), lesser CV was obtained with straight grooved disc CV values of the straight grooved spinning disc were lesser at 150 cc min^{-1} flow rate than at 75 cc min^{-1} flow rate The flow of liquid might not be uniform at low flow rate probably due to discontinuity of liquid flow Thus the uniformity of spray distribution were poor at low flow rate

Concurrent to the spray patternator tests conducted with inclined grooved and straight grooved spinning discs with 75 and 150 cc min^{-1} flow rates, amperage readings of the DC power supply were taken for each test From these readings, power consumption of the DC motor was found for each test The flow rate and type of spinning disc with minimum power consumption were found from Fig 4 31

As the spinning disc speed increased, power consumption increased for both the types of discs with both the flow rates The straight grooved spinning disc had lesser power consumption when compared to the inclined grooved spinning disc at both the flow rates of 75 and 150 cc min^{-1} The atomization process in inclined grooved spinning disc consumed more power due to more length of each groove as compared to straight grooves The liquid ligaments were to travel relatively longer distances before leaving the disc periphery in the case of inclined grooves Motor torque and spinning disc radius are constant Hence force exerted on each drop is constant But due to relatively increased length of travel by the individual drops on the inclined grooves, power consumption was higher

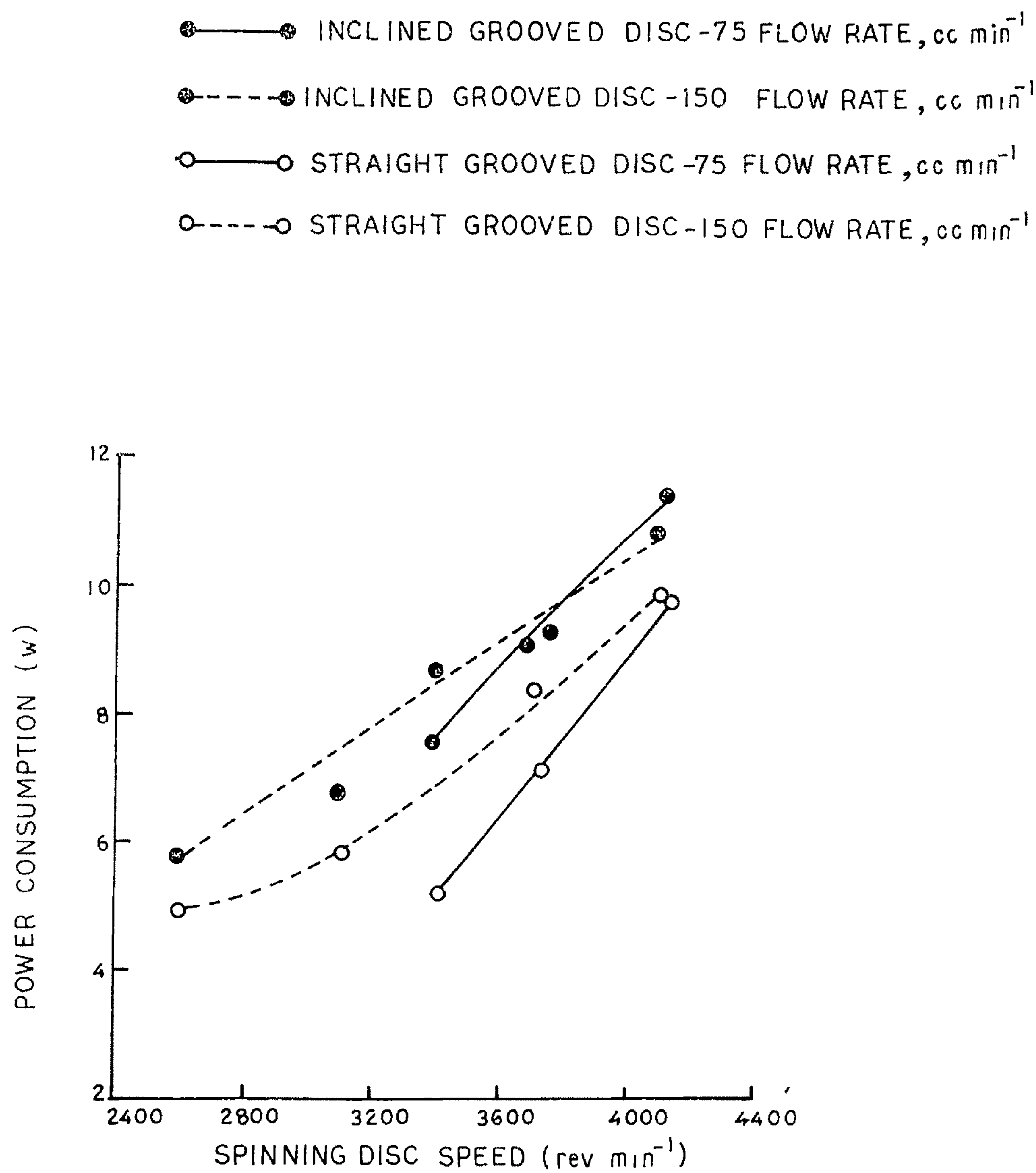


FIG.4.31 EFFECT OF SPINNING DISC SPEED ON POWER CONSUMPTION

As the liquid flow rate increased from 75 to 150 cc min^{-1}, rotational speed of the inclined grooved spinning disc decreased by 17.67 percent whereas the speed of the straight grooved spinning disc decreased by 9 28 per cent The flow path of the liquid from the point of emission towards the disc periphery is radial due to the centrifugal force caused by the disc rotation In the case of straight grooves, the flow path of liquid ligaments coincides with the grooves whereas in the case of inclined grooves the flow path of liquid ligaments and the direction of grooves differ This might have caused the deccelerating effect on the disc rotation Hence the speed of inclined grooved disc is lesser to straight grooved disc

ii Atomization characteristics

VMD and NMD of spray spectra of inclined grooved and straight grooved spinning discs with 75 and 150 cc min^{-1} flow rates at the rated 12 V for the droplet samples captured at 200, 400, 600, 800 and 1000 mm distances from the centre of spinning disc are presented in Table 4 22 and 4 23

VMD and NMD of the spray spectra were lesser for the straight grooved spinning disc when compared to the inclined grooved spinning disc at all the sampling distances of 200 to 1000 mm at both the flow rates of 75 and 150 cc min^{-1} , Fig 4 32 and 4 33 The mean spray droplet size was lesser for the straight grooved disc owing to the higher rotational speed of the disc as compared to inclined grooved disc

As the distance from the disc centre increased, droplet size increased at an increasing rate for both the discs and flow rates This concurs with the results reported

Table 4.22 Atomization characteristics of inclined grooved and straight grooved spinning discs at 75 rev min^{-1} flow rate

Ambient temperature	26 5°C (db)
Relative humidity	64 per cent

Sl no	Horizontal distance from spinning disc centre (mm)	Inclined grooved spinning disc (3050 rev min^{-1})			Straight grooved spinning disc (3890 rev min^{-1})		
		VMD (μm)	NMD (μm)	VMD/ NMD	VMD (μm)	NMD (μm)	VMD/ NMD
1	200	127 17	120 39	1 056	107 15	102 29	1 048
2	400	148 53	139 83	1 062	141 18	135 60	1 041
3	600	199 76	192 23	1 039	159 43	155 67	1 024
4	800	248 05	245 28	1 011	205 36	199 72	1 028
5	1000	276 03	271 02	1 018	257 38	255 75	1 006

Table 4.23. Atomization characteristics of inclined grooved and straight grooved spinning discs at 150 rev min^{-1} flow rate

Ambient temperature	26 5°C (db)
Relative humidity	64 per cent

Sl no	Horizontal distance from spinning disc centre (mm)	Inclined grooved spinning disc (2511 rev min^{-1})			Straight grooved spinning disc (3529 rev min^{-1})		
		VMD (μm)	NMD (μm)	VMD/ NMD	VMD (μm)	NMD (μm)	VMD/ NMD
1	200	124 04	117 89	1 052	99 20	94 61	1 049
2	400	142 94	138 11	1 035	120 53	111 32	1 083
3	600	169 26	164 71	1 028	154 13	147 15	1 047
4	800	235 92	219 03	1 077	198 73	191 63	1 037
5	1000	297 31	273 00	1 089	249 31	244 22	1 020

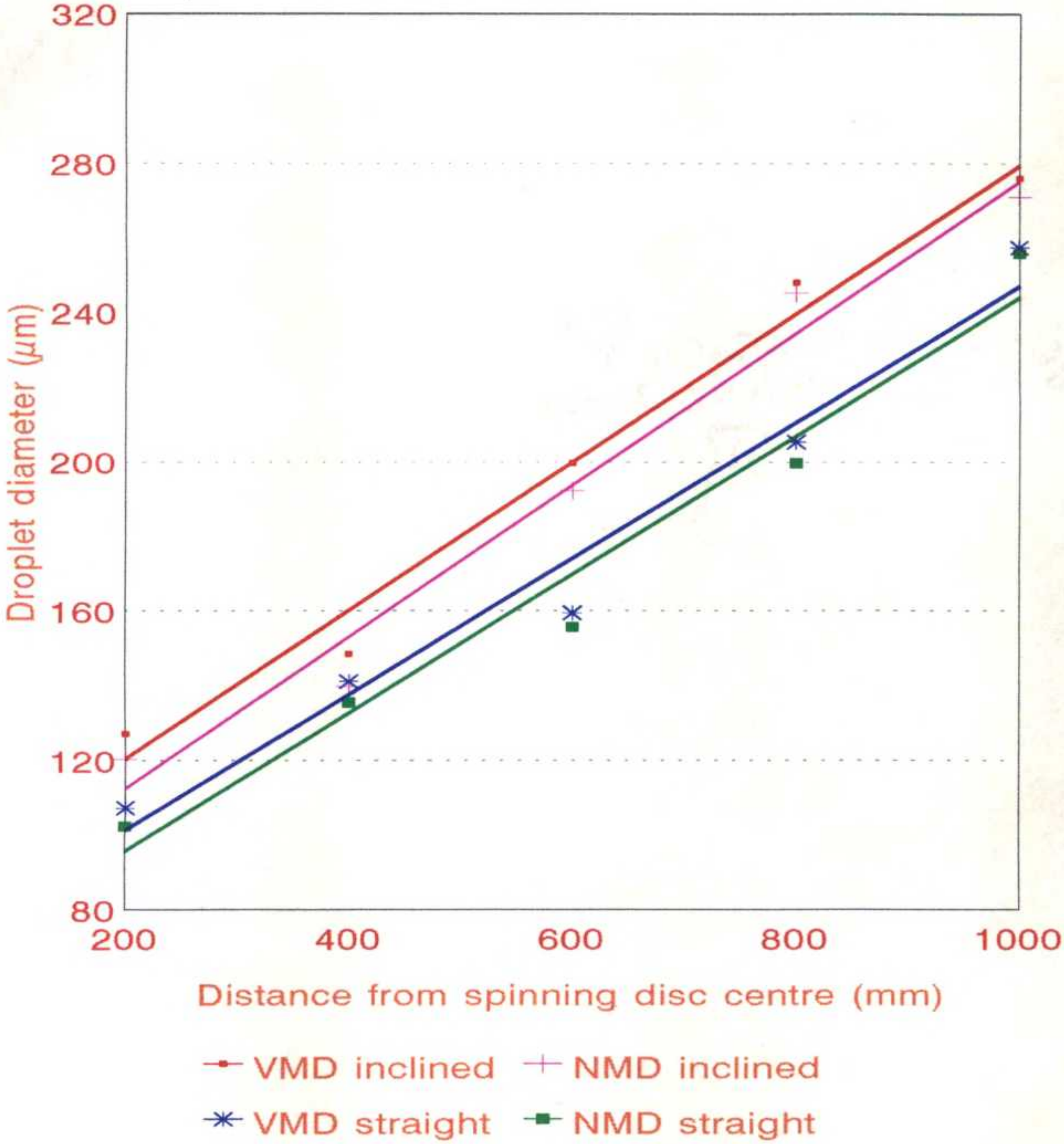


Fig. 4.32 Atomization characteristics of inclined and straight grooved spinning discs at 75 cc min^{-1} flow rate

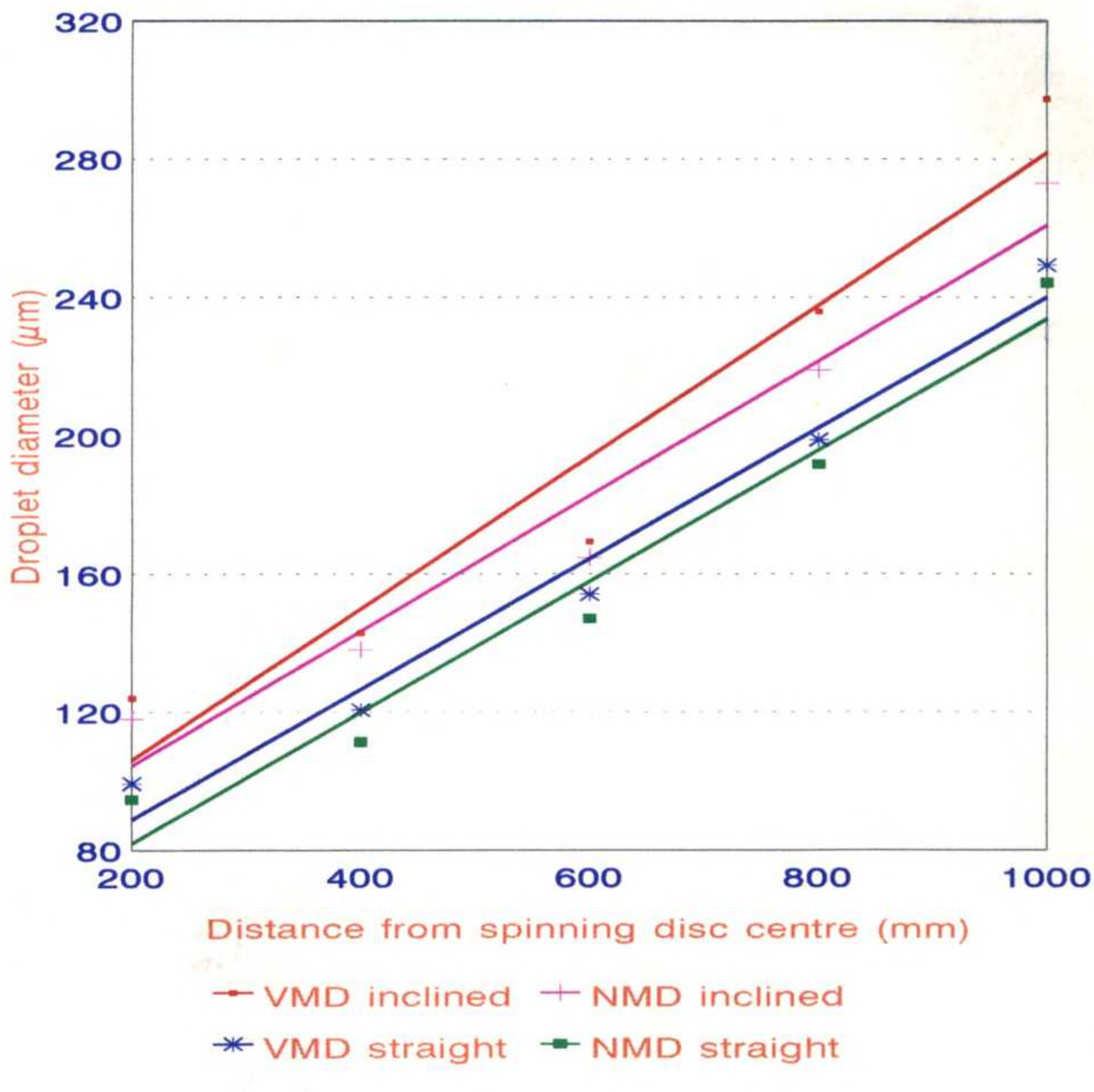


Fig. 4.33 Atomization characteristics of inclined and straight grooved spinning discs at 150 cc min^{-1} flow rate

by Matthews(1973) that the mean droplet sizes would increase appreciably with increase in the sampling distances in the 12 V battery powered spinning disc sprayer. Hence the distance at which the spray droplet samples are recorded is one of the important factors that influence the mean droplet size (Singh and Bindra, 1975)

VMD NMD ratio of the spray spectra was lesser for the straight grooved spinning disc as compared to the inclined grooved spinning disc at the flow rate of 75 cc min^{-1} at all the sampling distances, Fig 4 34 At the normal operating distance of 450 to 1000 mm from the disc centre, the VMD NMD ratio of straight grooved disc was lesser than that of inclined grooved disc This reveals that uniformity of spray droplet size distribution is better for the straight grooved disc

The above results indicate that the straight grooved spinning disc performed better when compared to the inclined grooved spinning disc in terms of lesser power consumption, lower CV, lesser spray droplet size and more closeness of VMD NMD ratio to unity Therefore subsequent tests were conducted with a straight grooved plastic spinning disc to find the components of power consumption, atomization characteristics and energy release pattern of battery of the 12 V DC motor operated spinning disc sprayer

b. Components of power consumption

Current, power consumption and rotational speed of 12 V DC motor at varying voltage levels from 6 to 12 V at no load and at the two controlled liquid flow rates of 75 and 150 cc min^{-1} are presented in Table 4 24 Power consumption increased linearly

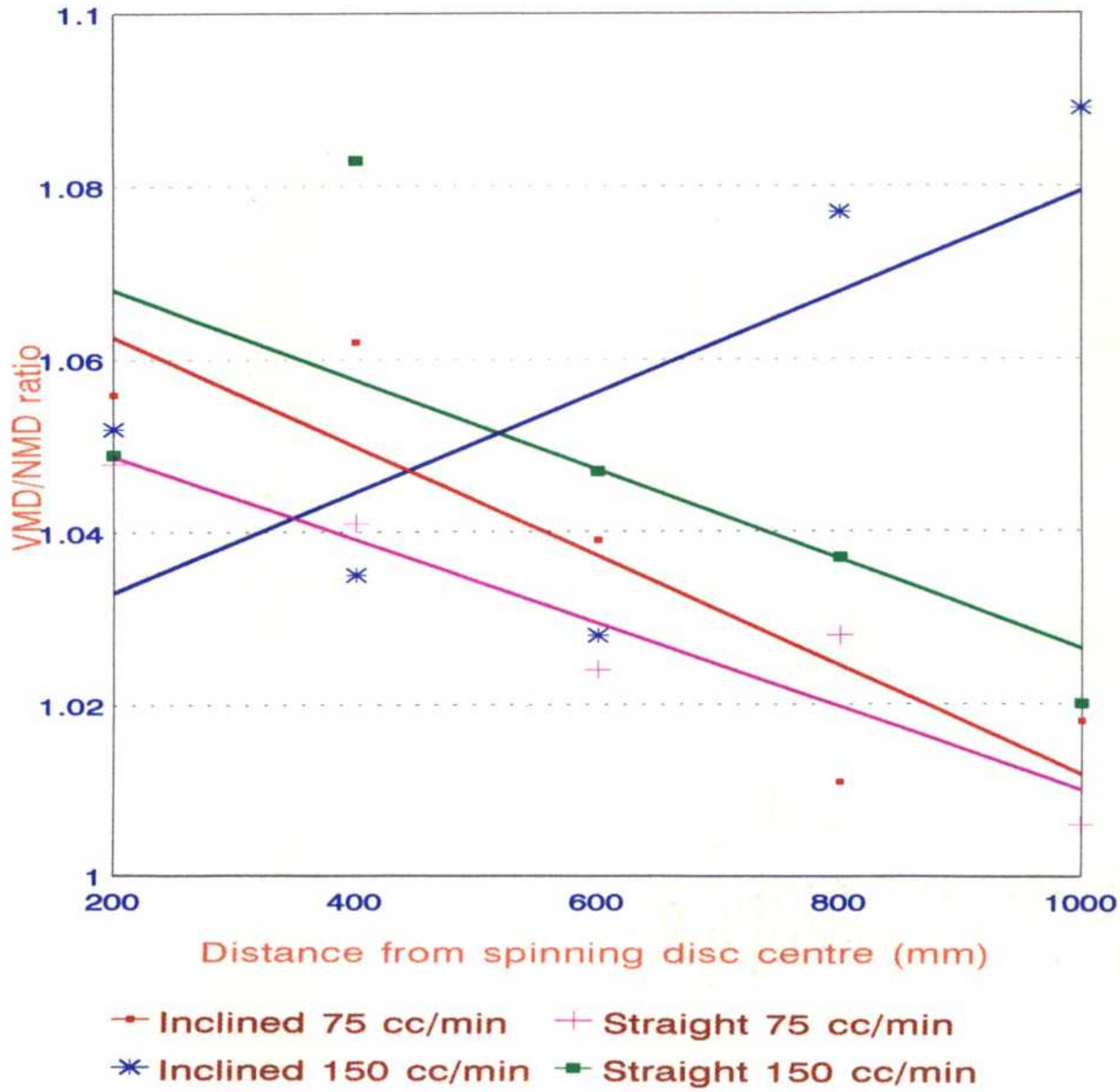


Fig 4.34 Uniformity of droplet size distribution for inclined and straight grooved spinning discs

Table 4.24. Components of power consumption for centrifugal spraying system

Sl no	Voltage (V)	No load Current (A)	No load Power (W)	No load Spinning disc speed (rev min^{-1})	75 cc min^{-1} flow rate Current (A)	75 cc min^{-1} flow rate Power (W)	75 cc min^{-1} flow rate Spinning disc speed (rev min^{-1})	150 cc min^{-1} flow rate Current (A)	150 cc min^{-1} flow rate Power (W)	150 cc min^{-1} flow rate Spinning disc speed (rev min^{-1})
1	6	0 34	2 04	2076	0 35	2 10	2058	0 39	2 34	2040
2	7	0 37	2 59	2325	0 38	2 66	2300	0 41	2 87	2275
3	8	0 39	3 12	2723	0 40	3 20	2685	0 44	3 52	2650
4	9	0 40	3 60	3125	0 31	3 69	3100	0 46	4 14	3074
5	10	0 41	4 10	3704	0 42	4 20	3565	0 47	4 70	3552
6	11	0 42	4 61	3913	0 45	4 95	3885	0 49	5 39	3850
7	12	0 44	5 28	4300	0 47	5 64	4282	0 51	6 12	4243

as voltage increased at no load and load, Fig 4 35. With high flow rate of 150 cc min^{-1}, power consumption of the motor was higher as compared to 75 cc min^{-1} flow rate There was no appreciable difference between power consumption at no load and 75 cc min^{-1} flow rate. The mean rate of increase in power consumption per unit increase in voltage was 0.63 W Maximum power consumption at the rated 12 V of the motor was 6.12 W at 150 cc min^{-1} flow rate, 5 64W at 75 cc min^{-1} flow rate and 5.28W at no load

Spinning disc speed increased linearly as voltage increased from 6 to 12 V at no load and load, Fig. 4 36 Variations in spinning disc speed was not appreciable when flow rate increased at all the voltage levels Minimum spinning disc speed (6V) at no load, 75 and 150 cc min^{-1} flow rates were 2076, 2058 and 2040 rev min^{-1} respectively The corresponding maximum spinning disc speeds (12 V) were 4300, 4282 and 4243 rev min^{-1} The spinning disc distributed more amount of liquid per unit time at higher liquid flow rate and hence power consumption of the DC motor increased at higher flow rate

c. Atomization characteristics of 12 V DC motor operated spinning disc sprayer

Experimental data collected to study the atomization characteristics of straight grooved 98 mm OD plastic spinning disc with two flow rates at 5 levels of disc speed for the spray droplets sampled at 600,800 and 1000 mm distances from disc centre are presented in Table 4 25 and 4 26.

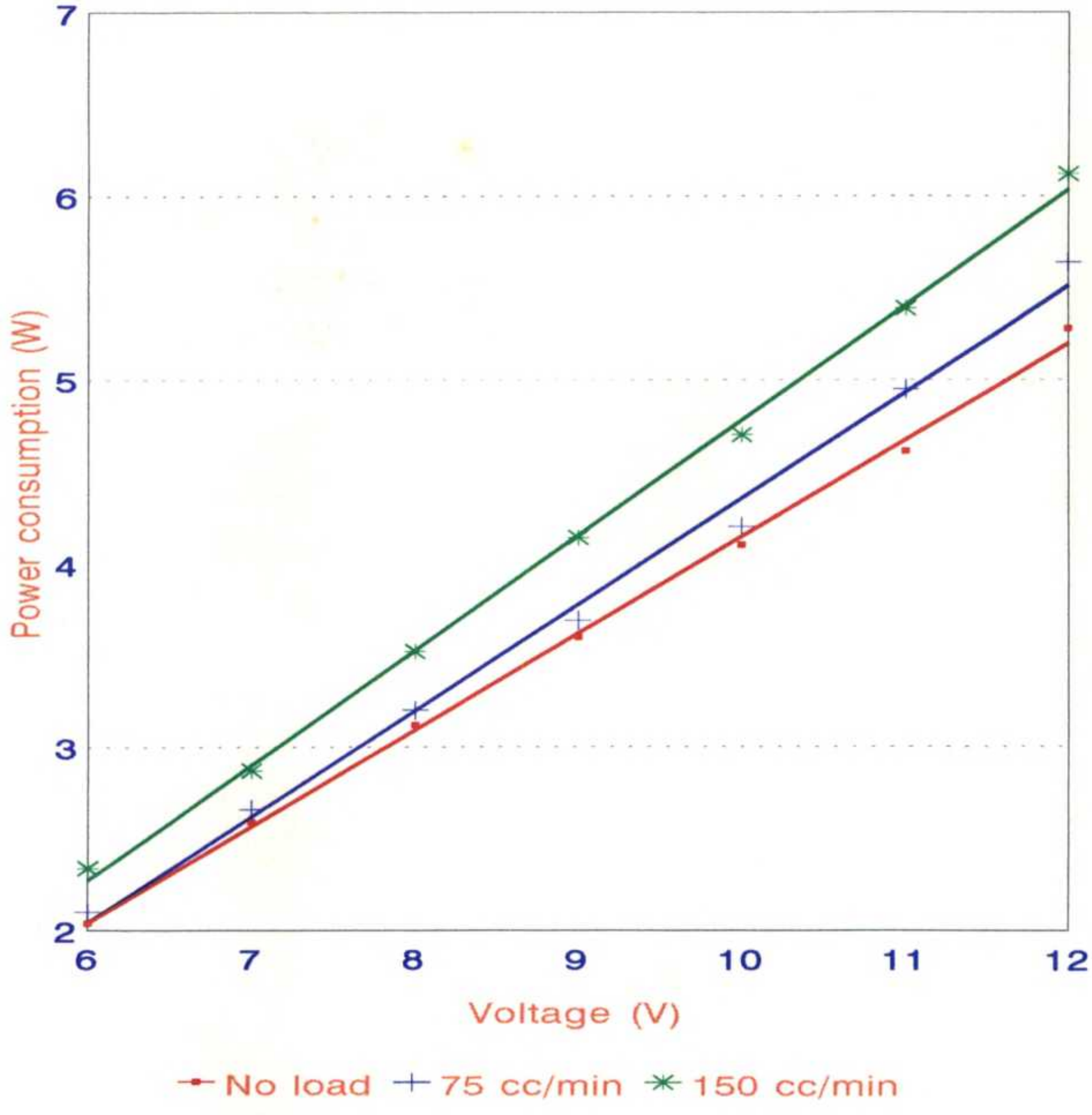


Fig 4.35 Power consumption for centrifugal spraying system

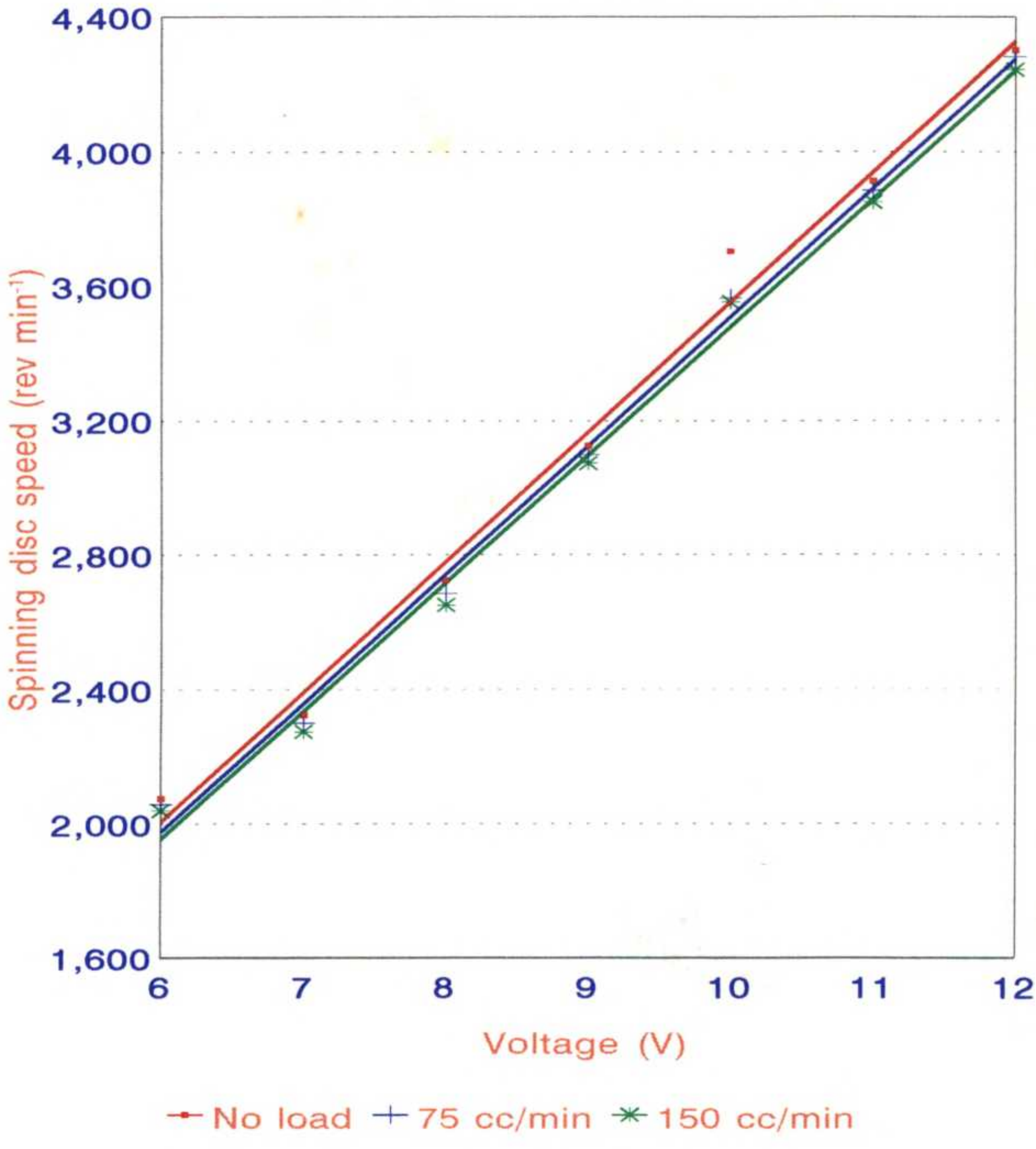


Fig 4.36 Spinning disc speed at varying voltage

Table 4. 25. Effect of spinning disc speed on atomization characteristics at 75 cc min^{-1} flow rate

Ambient temperature 30 5°C (db)
Relative humidity 56 0 per cent

Sl no	Spinning disc speed (rev min^{-1})	Horizontal distance from spinning disc centre (mm)								
		600			800			1000		
		VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD
1	2825	244 20	245 50	0 995	286 90	277 40	1 034	325 30	327 80	0 992
2	3200	224 60	226 10	0 993	262 00	261 00	1 004	302 40	301 50	1 003
2	3575	226 30	219 60	1 031	256 20	250 60	1 022	288 30	288 00	1 001
4	3925	208 20	207 80	1 002	242 40	242 40	1 000	282 70	282 90	0 999
5	4300	205 70	204 90	1 004	234 70	234 10	1 003	271 00	270 00	1 004

Table 4.26 Effect of spinning disc speed on atomization characteristics at 150 cc min^{-1} flow rate

Ambient temperature 30 5°C (db)
Relative humidity 56 0 per cent

Sl no	Spinning disc speed (rev min^{-1})	Horizontal distance from spinning disc centre (mm)								
		600			800			1000		
		VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD
1	2725	225 20	229 40	0 982	270 30	276 60	0 992	314 40	313 40	1 003
2	3125	218 30	228 20	1 000	267 30	266 50	1 003	298 80	297 30	1 005
3	3475	224 30	223 00	1 006	256 50	256 30	1 001	292 80	284 40	1 030
4	3900	223 60	220 60	1 014	246 20	246 00	1 001	289 40	290 50	0 996
5	4275	214 30	213 80	1 002	244 20	243 00	1 005	281 20	288 20	0 976

Minimum mean VMD and NMD of the spray spectra were 205.70 and 204.90 µm at 75 cc min^{-1} flow rate at 600 mm distance from disc centre and at 4300 rev min^{-1} spinning disc speed (1 004 VMD NMD ratio) At 150 cc min^{-1} flow rate, corresponding VMD and NMD were 214.30 and 213 80 µm (1 002 VMD NMD ratio)

Increasing the spinning disc speed had the effect of linearly reducing VMD as well as NMD for both the liquid flow rates This phenomenon is in conformity with the studies conducted by Bals (1969), Dombrowski and Lloyd (1974), Boize and Dombrowski (1976), Heinje (1978), Kamiya and Kayano (1979), Shastry (1981) and Bode *et al* (1983) Droplet size decreased with increasing disc speed since increase in disc speed imparted more energy to the atomizing process

VMD and NMD were close to each other at all the levels of spinning disc speed at both the flow rates and at all the three sampling distances This shows the ability of the 12 V DC motor operated spinning disc to produce spray droplets without much variations in size The slopes of the droplet diameter vs spinning disc speed lines in Fig.4 37 and 4 38 indicate that the rate of decrease in drop size with increase in disc speed remains the same at all the three sampling distances The rate of decrease in drop size was more at 75 cc min^{-1} flow rate than at 150 cc min^{-1} flow rate That means the reduction in drop size due to increase in disc speed was lesser at full flow rate than at fractional flow rate

At 75 cc min^{-1} flow rate, VMD and NMD values were close to each other at 600 and 1000 mm distances from disc centre At 800 mm distance, there was no

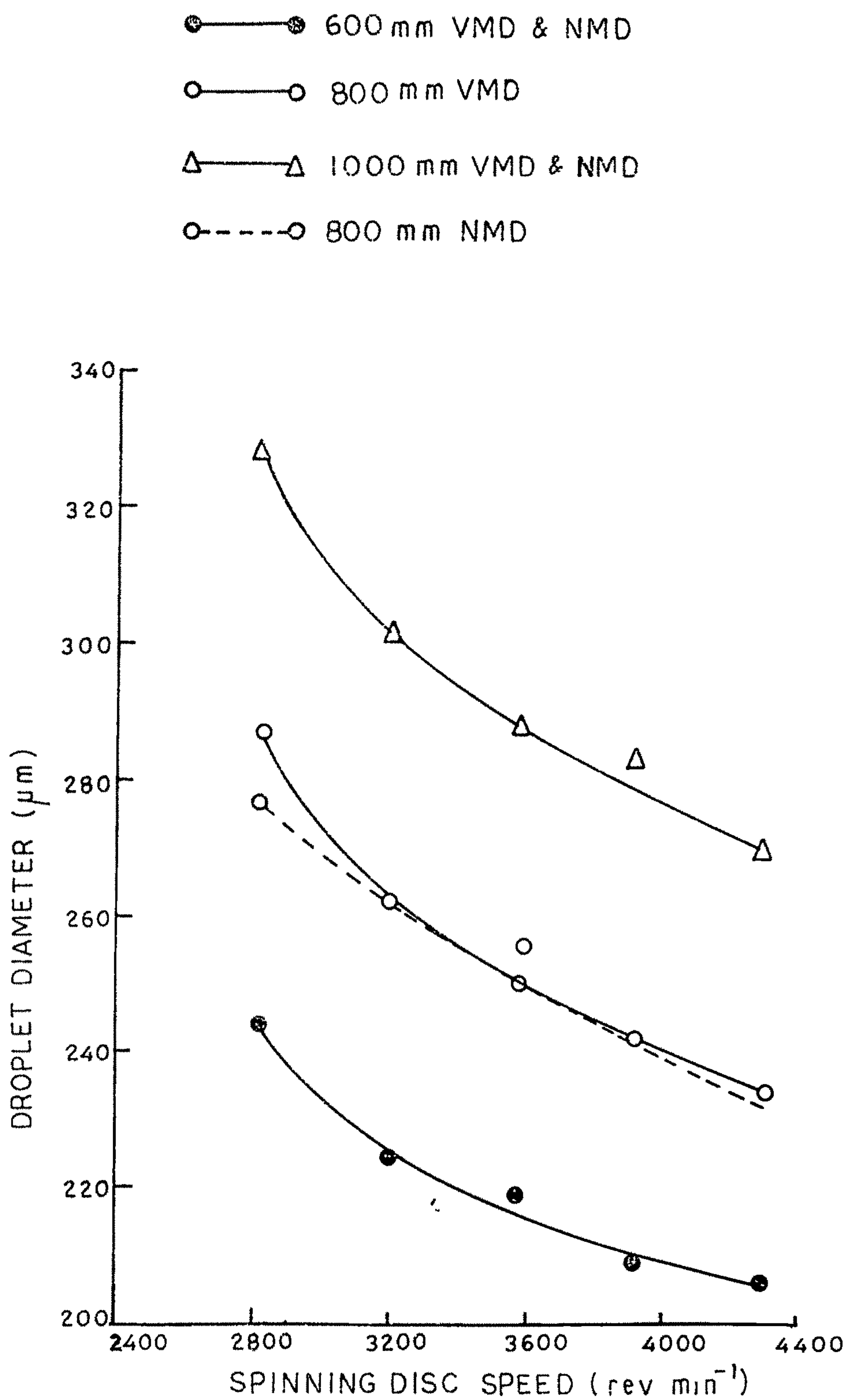


FIG.4.37 EFFECT OF SPINNING DISC SPEED ON ATOMIZATION CHARACTERISTICS ($75 cc\ min^{-1}$)

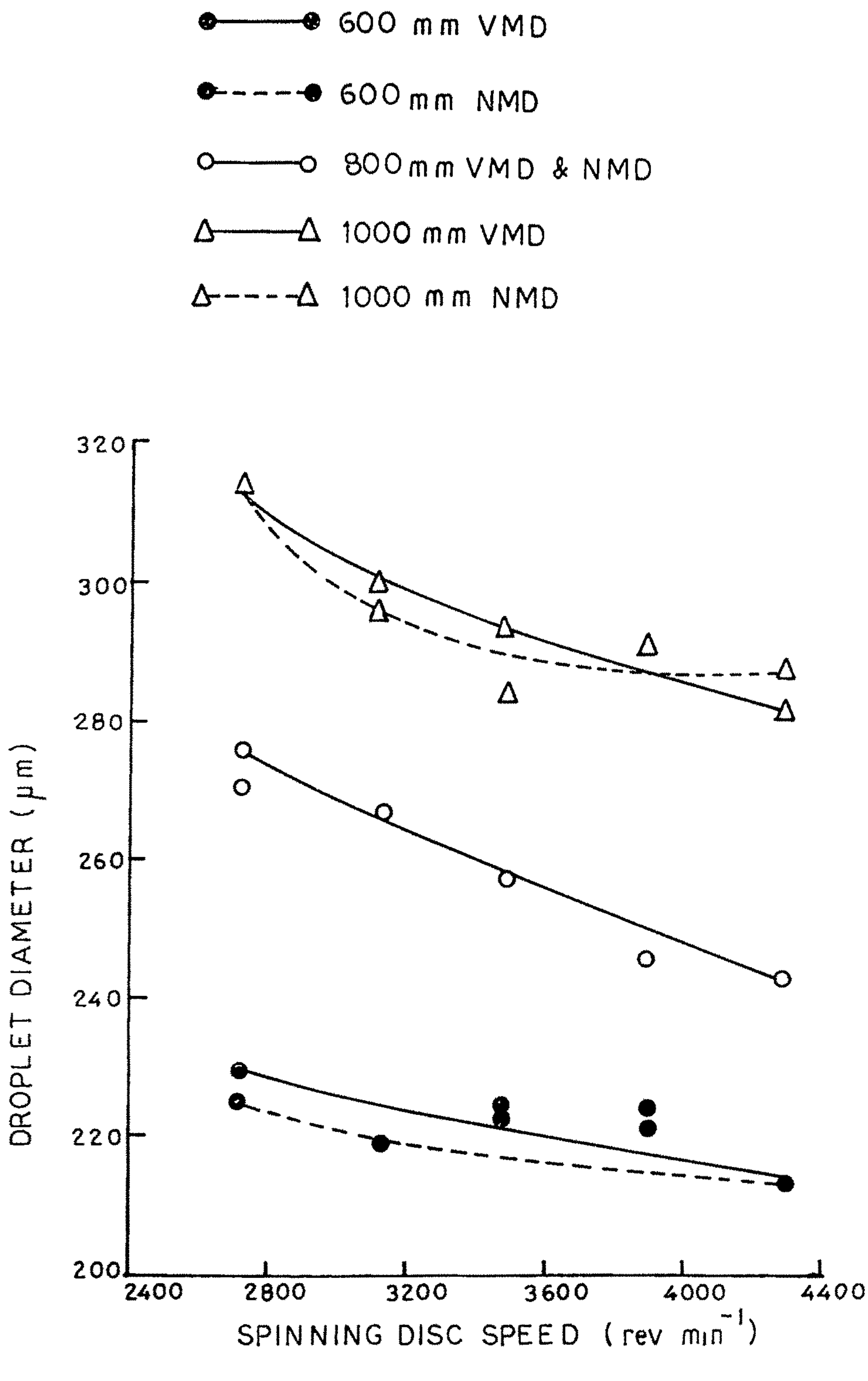


FIG. 4.38 EFFECT OF SPINNING DISC SPEED ON ATOMIZATION CHARACTERISTICS (150 cc min^{-1})

appreciable difference between VMD and NMD values. At 150 cc min^{-1} , VMD and NMD lines merged with other at 800 mm distance At 600 mm and 1000 mm distances the above two lines were close to each other

At the rated 12 V at 800 mm distance from the disc centre and at 75 cc min^{-1} flow rate, VMD and NMD of the main satellite spray cloud were 234 70 and 234 10 µm respectively Corresponding VMD and NMD at 150 cc min^{-1} flow rate were 244 20 and 243 00 µm At the rate 12 V as the distance from the disc centre increased from 600 to 1000 mm, VMD increased from 205 70 to 271 00 µm at 75 cc min^{-1} flow rate and from 214 30 to 281 20 µm at 150 cc min^{-1} flow rate Similar trend was observed for NMD

Increase in drop size with increase in sampling distance might be due to more distance of travel by the heavy droplets due to more centrifugal energy imparted upon them, overcoming the aerodynamic drag Bigger droplets are thrown to greater distances than smaller droplets due to large mass and greater centrifugal force ($m\omega^2 r$) Therefore droplet size increased as distance from disc centre decreased The droplet size increased as the flow rate increased which is in accordance with the results obtained by Frost (1981) and Derksen and Bode (1986)

Regression analysis of the data reveal that VMD (µm), NMD (µm), spinning disc speed in rev min^{-1}(s) and distance of droplet capture from disc centre in mm (d) were related as follows

At 75 cc min^{-1} flow rate,

VMD (μm) = 224 974 - 0 0314 s + 0 180 d (R^2 = 0 9793) (4 1)

NMD (μm) = 219 198 - 0 0308 s + 0 183 d (R^2 = 0.98) (4 2)

At 150 cc min^{-1} flow rate,

VMD (μm) = 159 289 - 0 0142 s + 0 185 d (R^2 = 0 9761) (4 3)

NMD (μm) = 159 770 - 0 0142 s + 0 184 d (R^2 = 0 9731) (4 4)

At 75 cc min^{-1} flow rate, VMD NMD ratios at 600 mm and 1000 mm distances from disc centre were the same, Fig 4 39 The VMD NMD ratio was higher at 800 mm distance as compared to the other sampling distances At 150 cc min^{-1} flow rate, VMD NMD ratios at 600 and 800 mm distances were close to each other, Fig 4 40 The VMD NMD ratio at 1000 mm distance was lesser to other two distances in the operating range of 3500 to 4300 rev min^{-1} disc speed

d. Energy release pattern of battery

Battery voltage, amperage and power consumption of motor and spinning disc speed during continuous operation with battery are given in Table 4 27. Battery voltage and power consumption of the motor decreased at constant rate upto 8 h of continuous operation, Fig 4.41 After 8 h of operation, the rate of decrease in voltage and power consumption increased with the operating time Similarly spinning disc speed decreased at a constant rate upto 8 h of operation, beyond which the spinning speed time curve drooped down drastically, Fig 4 42

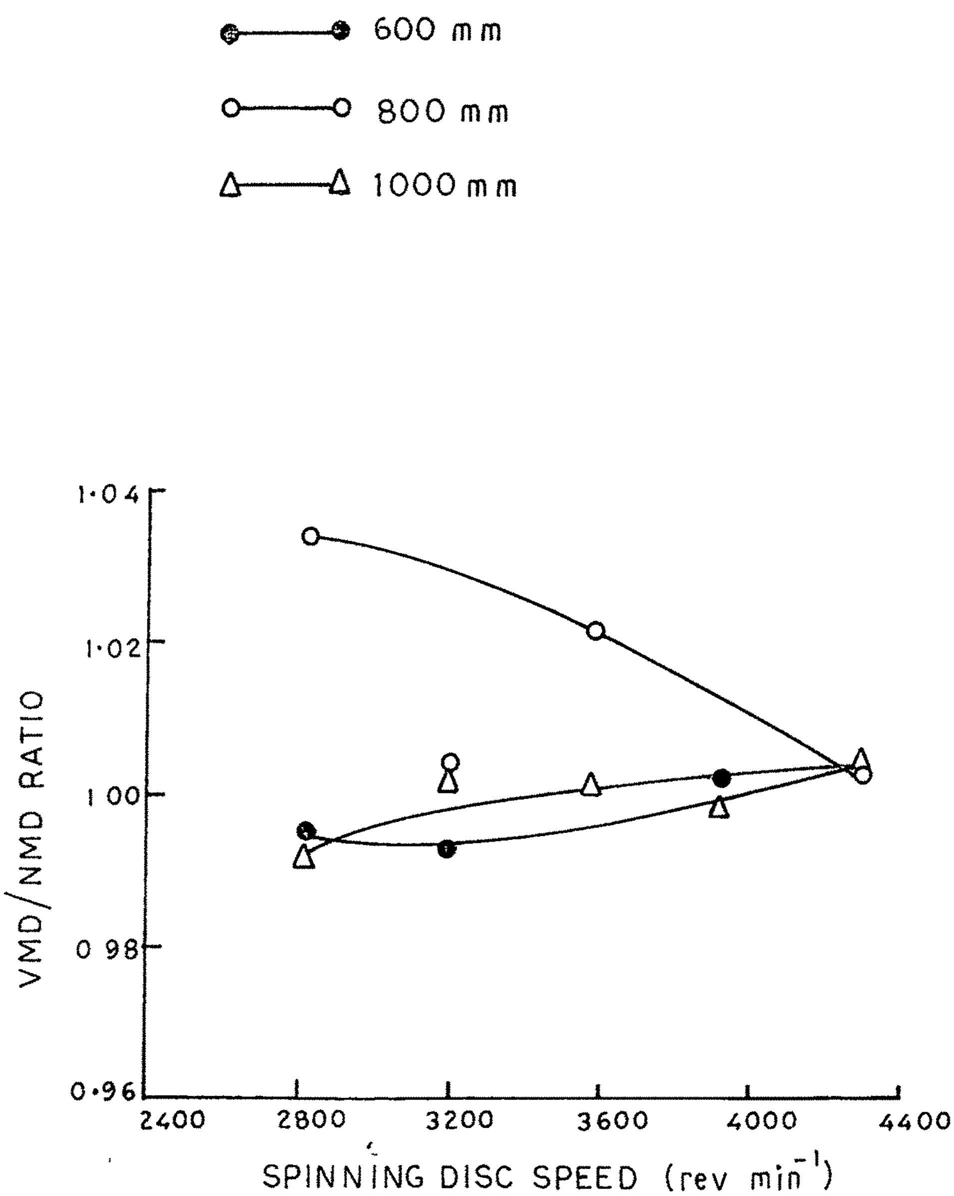


FIG. 4.39 EFFECT OF SPINNING DISC SPEED ON VMD/NMD RATIO (75 cc min^{-1})

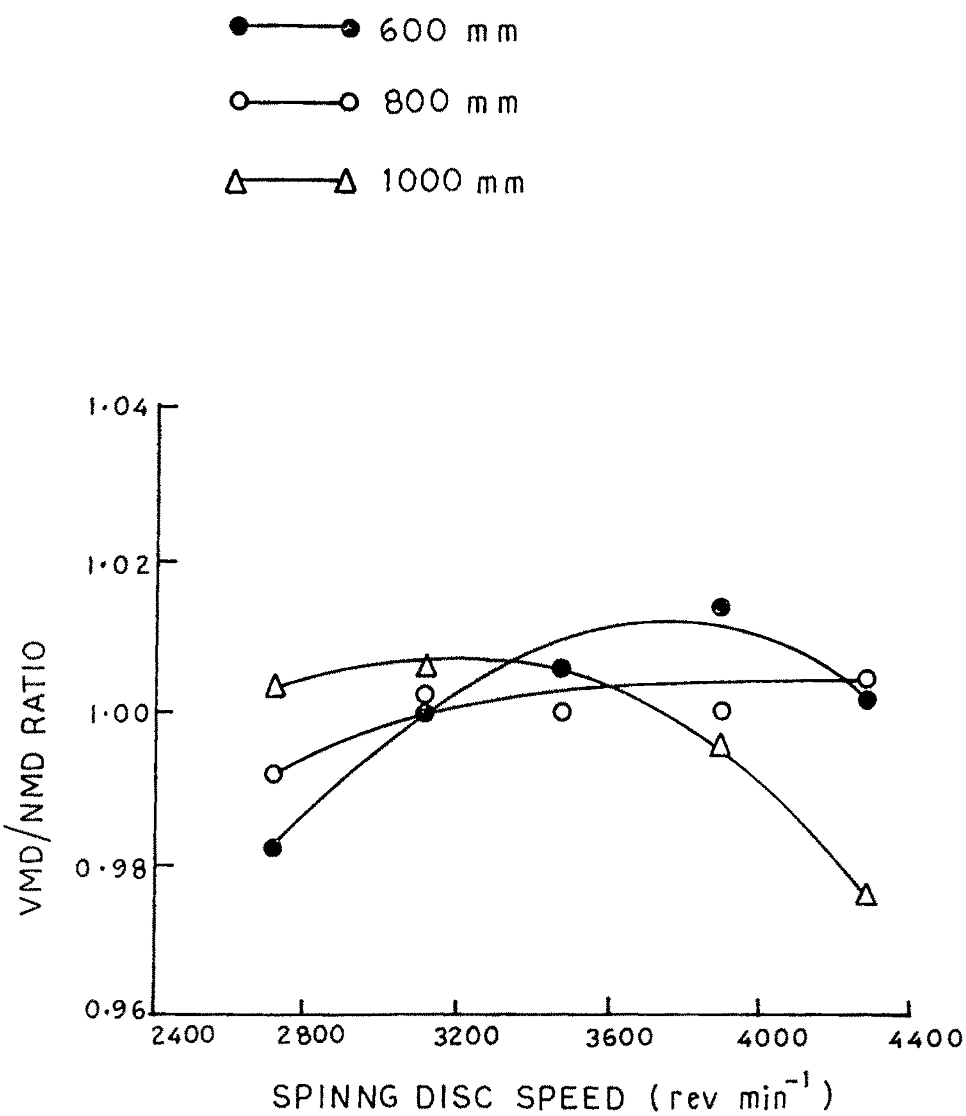


FIG.4.40 EFFECT OF SPINNING DISC SPEED ON VMD/NMD RATIO (150 cc min^{-1})

Table 4.27. Energy release pattern of battery for centrifugal spraying system

Sl no	Operating time (h)	Battery voltage (V)	Current (A)	Power consumption (W)	Spinning disc speed (rev min^{-1})
1	0	12 0	0 48	5 76	4080
2	1	11 8	0 47	5 55	4020
3	2	11 7	0 47	5 50	4000
4	3	11 6	0 46	5 34	3960
5	4	11 5	0 45	5 18	3938
6	5	11 4	0 44	5 02	3920
7	6	11 2	0 44	4 93	3901
8	7	11 1	0 43	4 77	3840
9	8	10 9	0 43	4 69	3781
10	9	9 7	0 41	3 98	3680
11	10	7 4	0 37	2 74	2661
12	11	4 9	0 32	1 57	1235

During the continuous operation upto 8 h, battery voltage reduced from 12 0 to 10 9 V and the spinning disc speed reduced from 4080 to 3780 rev min^{-1} In the above disc speed range, change in spray droplet size were not appreciable at all the sampling distances, Fig 4 38

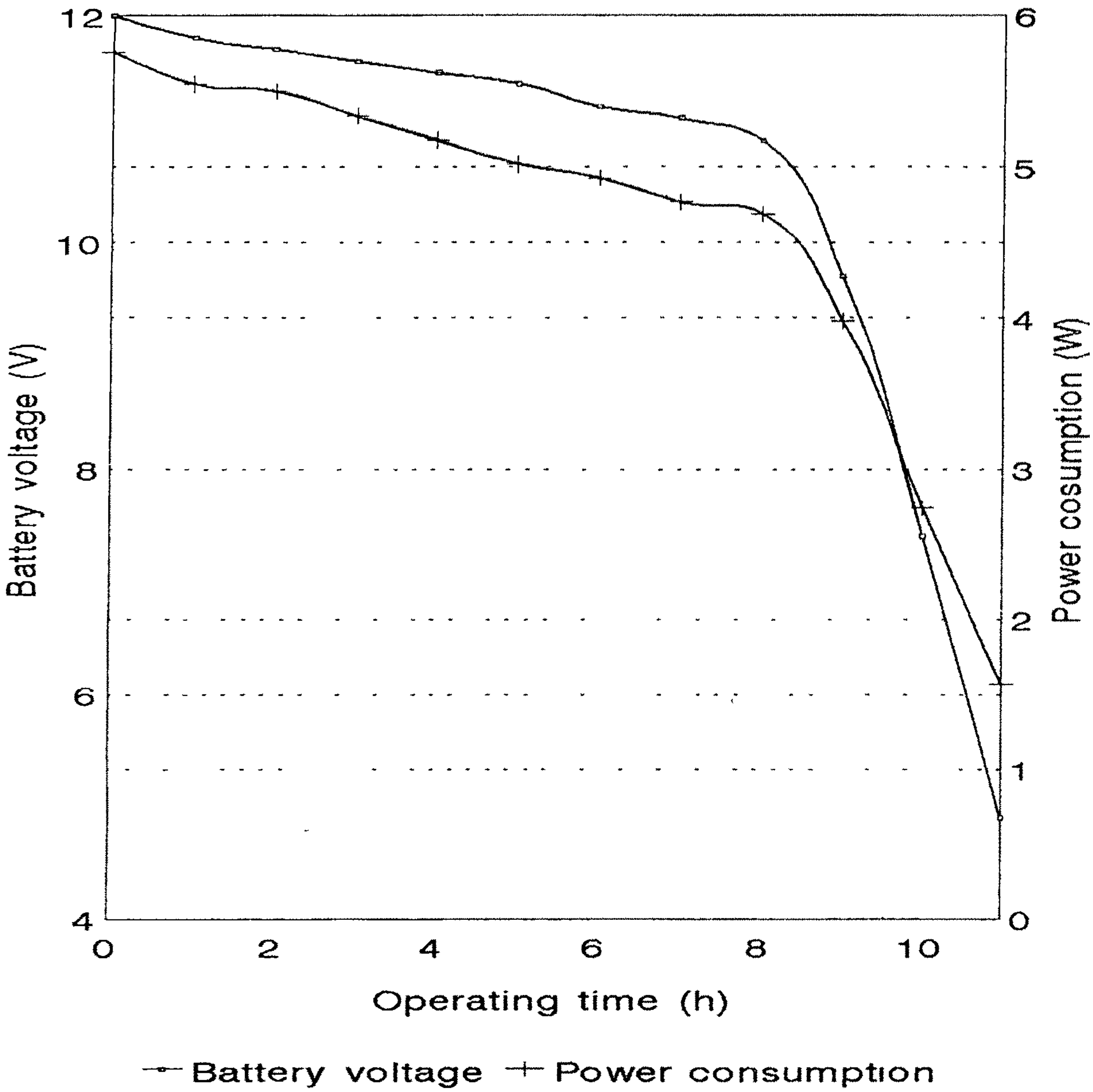


Fig 4.41 Energy release pattern of battery for centrifugal spraying system

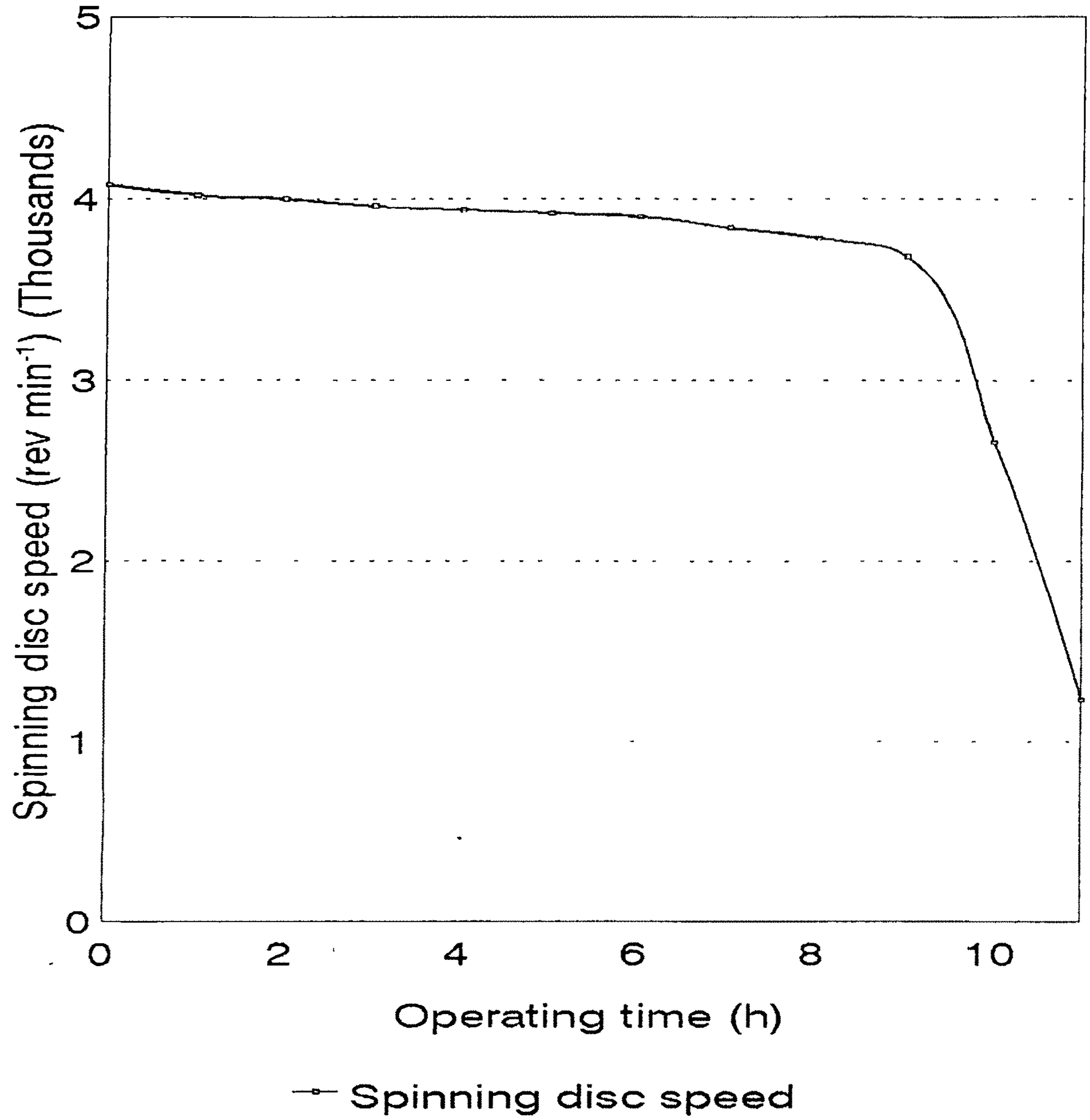


Fig. 4.42 Effect of operating time on spinning disc speed

4.4. Development of battery powered prototype spinning disc sprayer

Battery powered hydraulic, pneumatic and centrifugal spraying systems were compared The best system for operating with battery was selected Using the optimized operational and atomizer parameters, a battery powered prototype spinning disc sprayer was developed

4.4.1. Selection of spraying system

Battery powered hydraulic, pneumatic and centrifugal spraying systems were compared on the wattage basis of power consumption in terms of CV, VMD and VMD NMD ratio in Table 4 28 The CV for the three systems at different levels of power consumption are illustrated in Fig 4 43 Among the three spraying systems, minimum range of CV was obtained with centrifugal system A minimum CV of 11 per cent was obtained with 10 W power consumption

The ranges of power consumption for hydraulic, pneumatic and centrifugal spraying systems for obtaining 74 to 99, 46 to 55 and 11 to 25 per cent of CV were respectively 22 to 53, 30 to 61 and 5 to 10 W The above data show that among the three systems, centrifugal system is better in terms of minimum power requirement as well as minimum CV

The three types of spraying systems were compared in terms of VMD, Fig. 4.44 The ranges of VMD obtained for the above spraying systems were 242 to 307 μm, 234 to 350 μm and 244 to 270 μm respectively Here again the range was closer for the centrifugal system According to Himel (1969), optimum diameter of

Table.4.28. Comparative performance of battery powered spraying systems on the basis of power consumption

Sl no	Battery powered spraying system											
	Hydraulic				Pnuematic				Centnfugal			
	Power (W)	CV (%)	VMD (µm)	VMD/ NMD	Power (W)	CV (%)	VMD (µm)	VMD/ NMD	Power (W)	CV (%)	VMD (µm)	VMD/ NMD
1	22 00	99 77	307.03	1 199	30 24	54 13	349 30	1 277	3 52	26 29	270 30	0 992
2	26 91	88 76	290 56	1 192	37 08	54 03	239 25	1 239	4 14	20 54	267 30	1 003
3	33 90	81 63	256 47	1 136	44 40	53 85	257 61	1 355	4 70	14 65	256 50	1 001
4	42 35	77 10	244 37	1 108	53 46	52 37	234 22	1 252	5 39	18 29	246.20	1 001
5	53 16	74.09	242 03	1 106	63 12	45 60	202 27	1 228	6 12	11 65	244 20	1 005

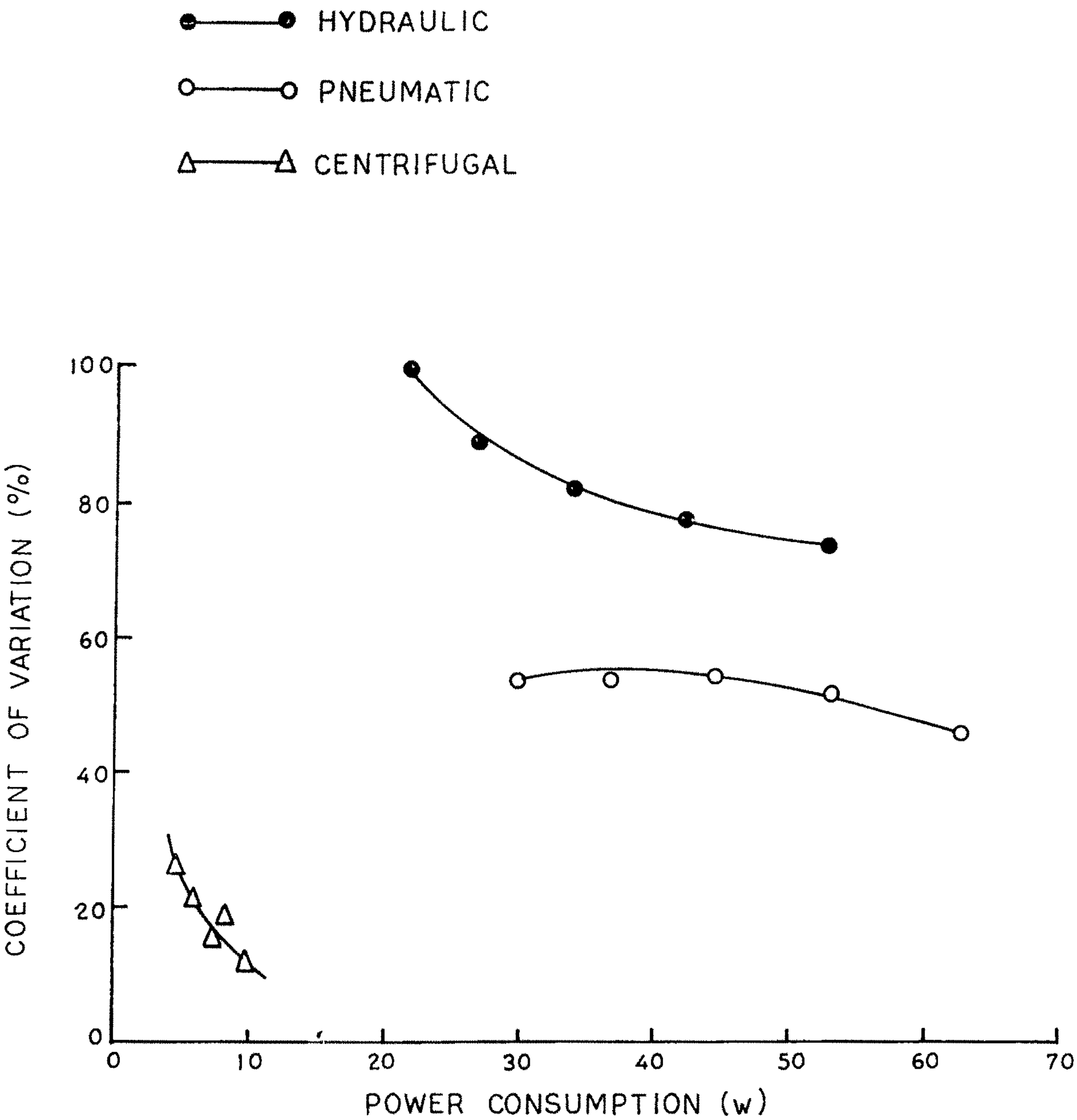


FIG.4.43 COMPARISON OF CV FOR BATTERY POWERED SPRAYING SYSTEMS

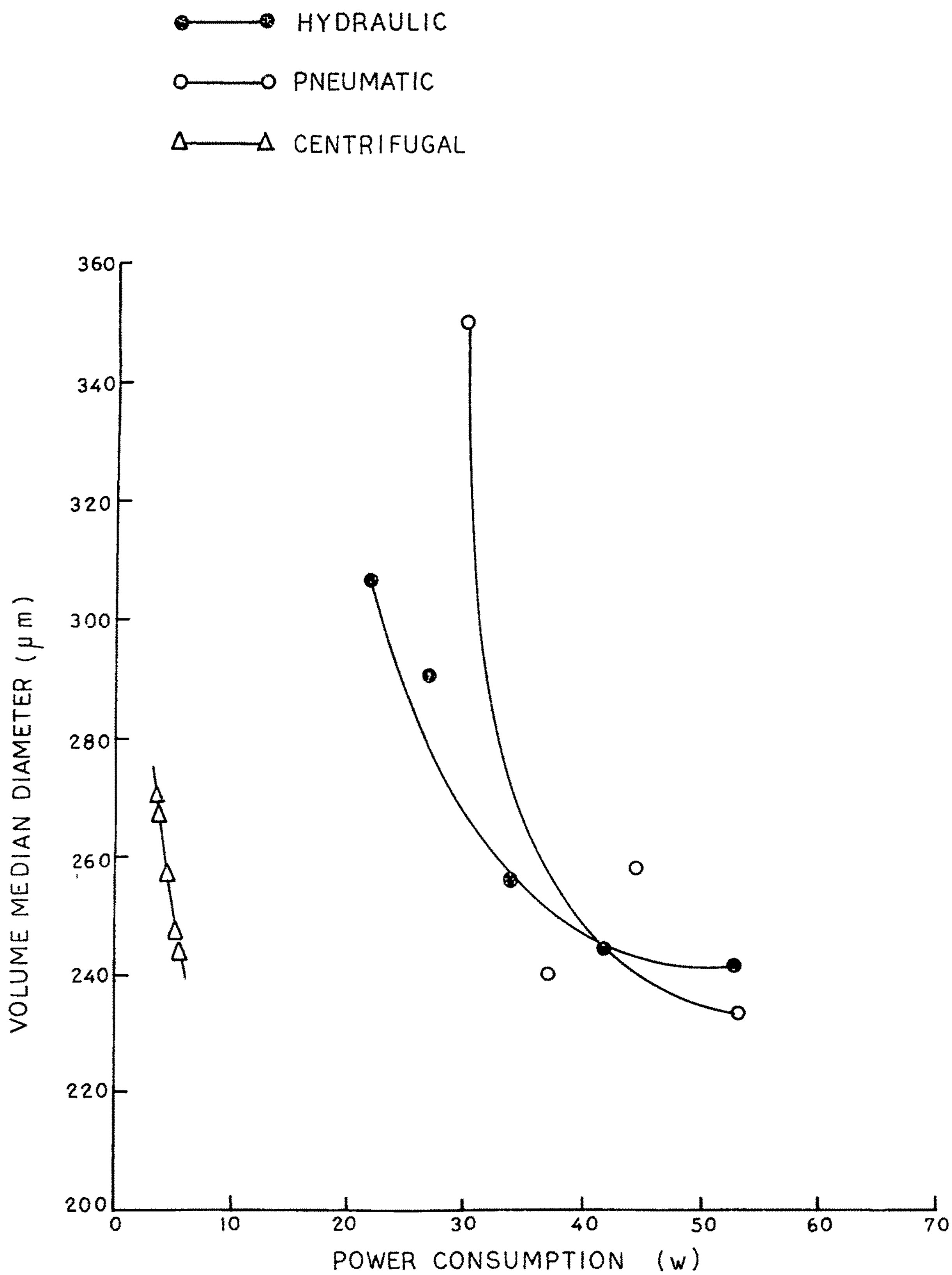


FIG. 4.44 COMPARISON OF VMD FOR BATTERY POWERED SPRAYING SYSTEMS

spray droplets for agricultural applications should be in the range of 200 to 300 μm. Culpin (1986) reported that there was no advantage in VMD higher than 280 μm from drift control point of view Centrifugal system alone meets the above requirements

Fig 4 45 shows that VMD NMD ratio of centrifugal system was more closer to unity when compared to the other two systems The VMD NMD ratio ranged from 1 10 to 1 20 for hydraulic system, from 1.23 to 1 26 for pneumatic system and from 0 99 to 1 01 for centrifugal system The VMD NMD ratio should be close to unity for uniform droplets according to Bode *et al* (1983) The VMD NMD ratios were closer to unity and the droplets produced were with narrow range for centrifugal spraying system

The three spraying systems were also compared in terms of mean rate of increase of power consumption per unit voltage increase, minimum CV, minimum VMD, minimum ratio of VMD NMD and effective service time of battery per cycle in Table 4 29. Though minimum VMD obtained with hydraulic and centrifugal spraying systems were close to each other, effective service time of battery per cycle was only 30 min for hydraulic system as compared to 480 min for centrifugal system, Fig. 4 46 The mean rate of increase in power consumption per unit voltage increase for the centrifugal system was 0 63 W when compared to 3 70 W for pneumatic system and 6 88 W for hydraulic system The highest power consumption of hydraulic system is attributed to the mechanical losses in driving the gear pump.

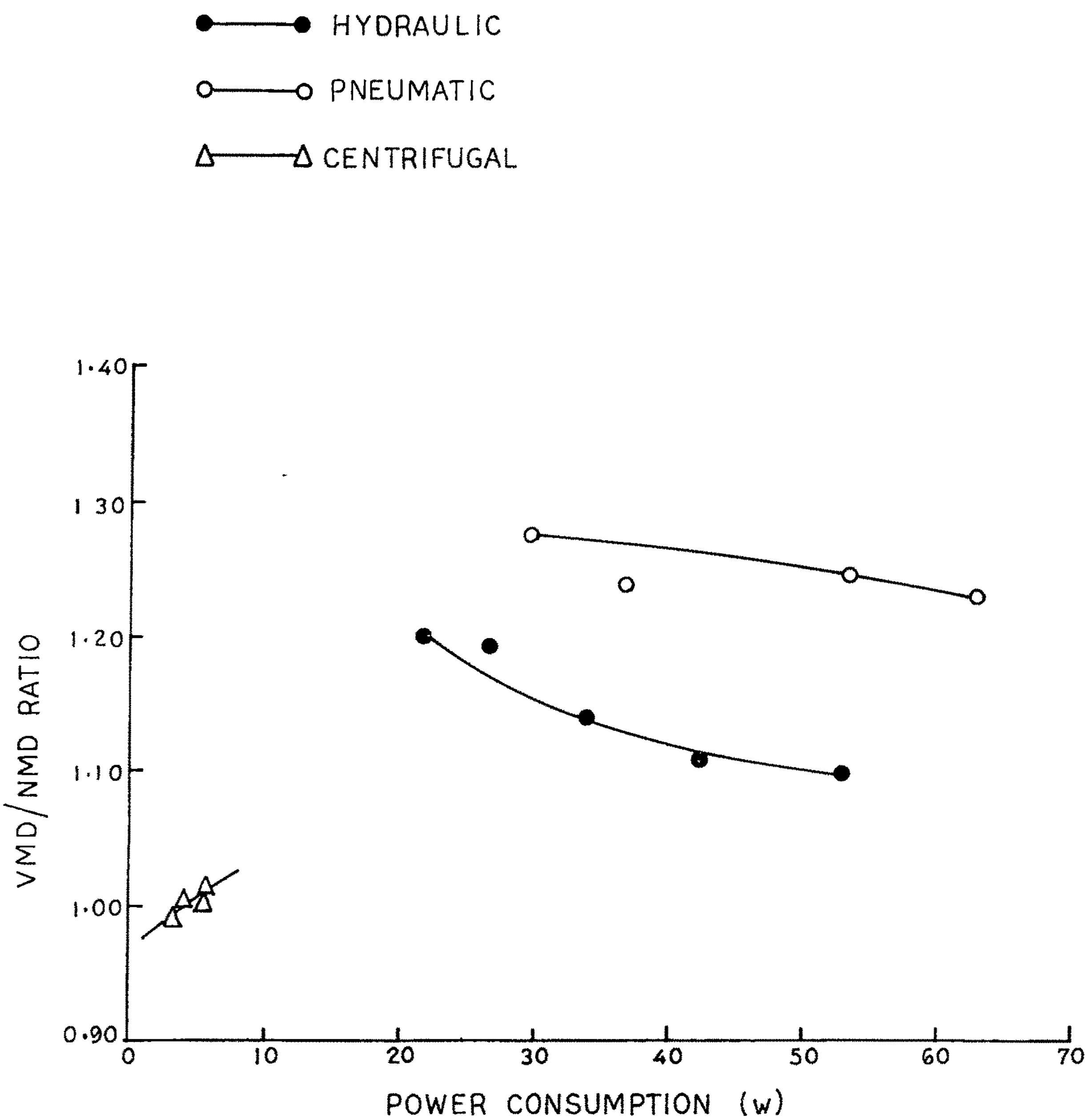


FIG.4.45 COMPARISON OF VMD/NMD RATIO FOR BATTERY POWERED SPRAYING SYSTEMS

Table 4.29. Comparison of battery powered spraying systems

Sl no	Spraying system	Mean rate of increase in power consumption per unit increase in voltage (W)	Minimum CV (%)	Minimum VMD (μm)	VMD/ NMD	Effective service time of battery/ cycle (min)
1.	Hydraulic	6 88	74 09	242 03	1 106	30
2	Pneumatic	3 70	45 60	250 98	1 325	60
3	Centrifugal	0 63	11 65	244 20	1 005	480

4.5. Performance characteristics of the prototype spinning disc sprayer

Performance characteristics of the prototype spinning disc sprayer were determined to find the power consumption, atomization characteristics, energy release pattern of battery and sound level produced

4.5.1. Power consumption

Power consumption and rotational speed of the DC motor of the prototype spinning disc sprayer at varying voltage levels are presented in Table 4 30 At full flow rate, the power consumption of the 6 V DC motor was 5 82 W whereas it was 6 12 W for 12 V DC motor, Table 4 24. In the case of 6 V spinning disc sprayer, for spraying alone excluding the power required for rotating the disc, 0 60 W power was expended where as in the case of 12 V spinning disc sprayer, 0.84 W power was expended at full flow rate

RESULTS AND DISCUSSION

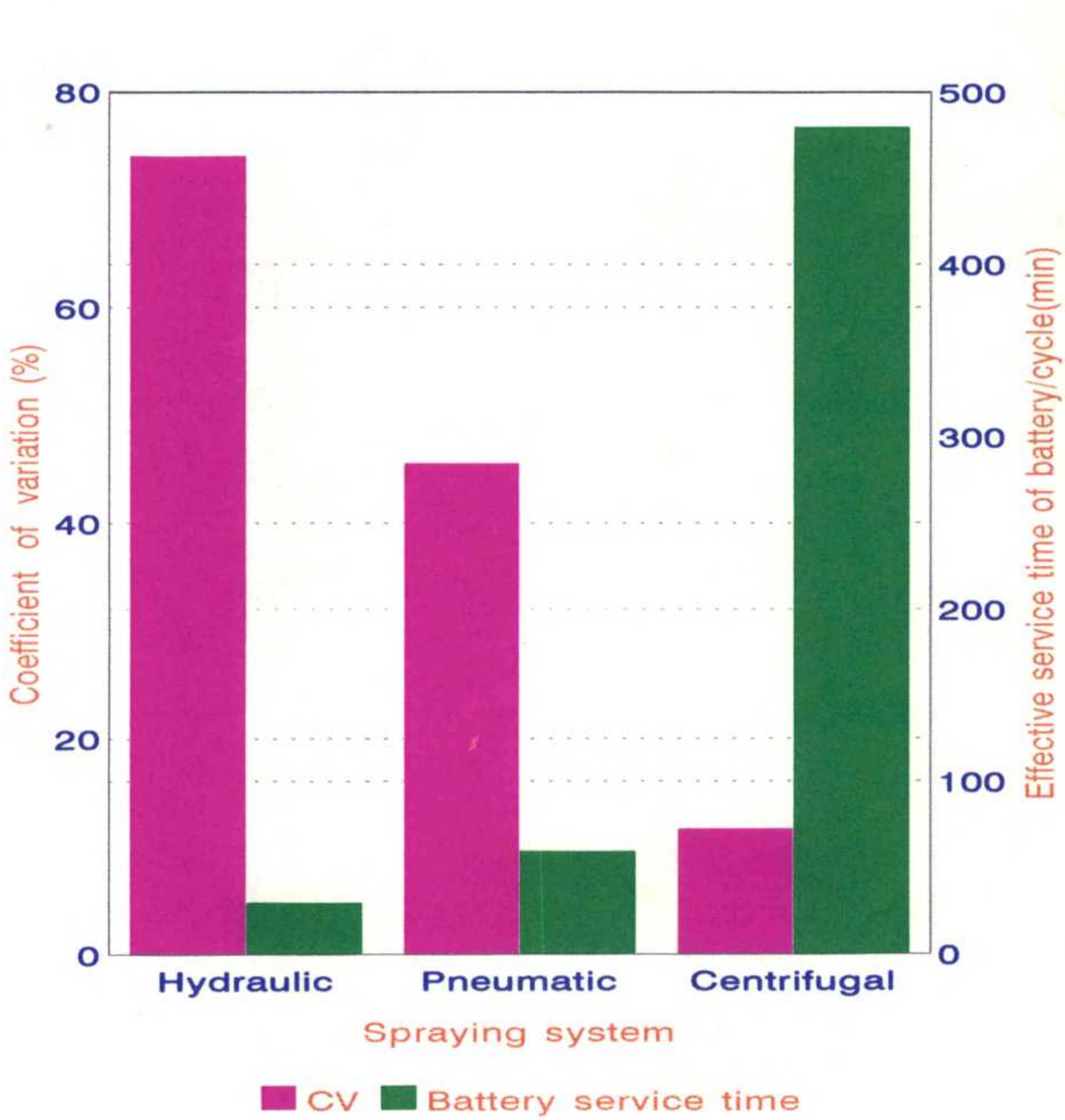


Fig 4.46 Comparison of battery powered spraying systems

Table 4.30. Power consumption of prototype spinning disc sprayer

Sl no	Voltage	No load			Load		
		Current	Power consumption	Spinning disc speed	Current	Power consumption	Spinning disc speed
	(V)	(A)	(W)	(rev min^{-1})	(A)	(W)	(rev min^{-1})
1	4 0	0 55	2 20	2841	0 65	2 60	2586
2	4 5	0 61	2 75	3278	0 73	3 29	2860
3	5 0	0 70	3 50	3510	0 79	3 95	3150
4	5 5	0 77	4 24	3705	0 87	4 79	3308
5	6 0	0 87	5 22	3927	0 97	5 82	3515

Power consumption curves of the 6 V DC motor at varying voltage both at no load and at load have the same trend of 12 V DC motor, Fig 4 47 Voltage vs spinning disc curves at no load and load of 6 V DC motor also have the same trend of 12 V DC motor, Fig 4 48 There was no appreciable difference in the power consumption of 6 V and 12 V motors at both the flow rates

4.5.2. Atomization characteristics

VMD and NMD of the prototype spinning disc sprayer at different levels of spinning disc speed for the droplet samples collected at 600, 800 and 1000 mm distances from disc centre are given in Table 4 31

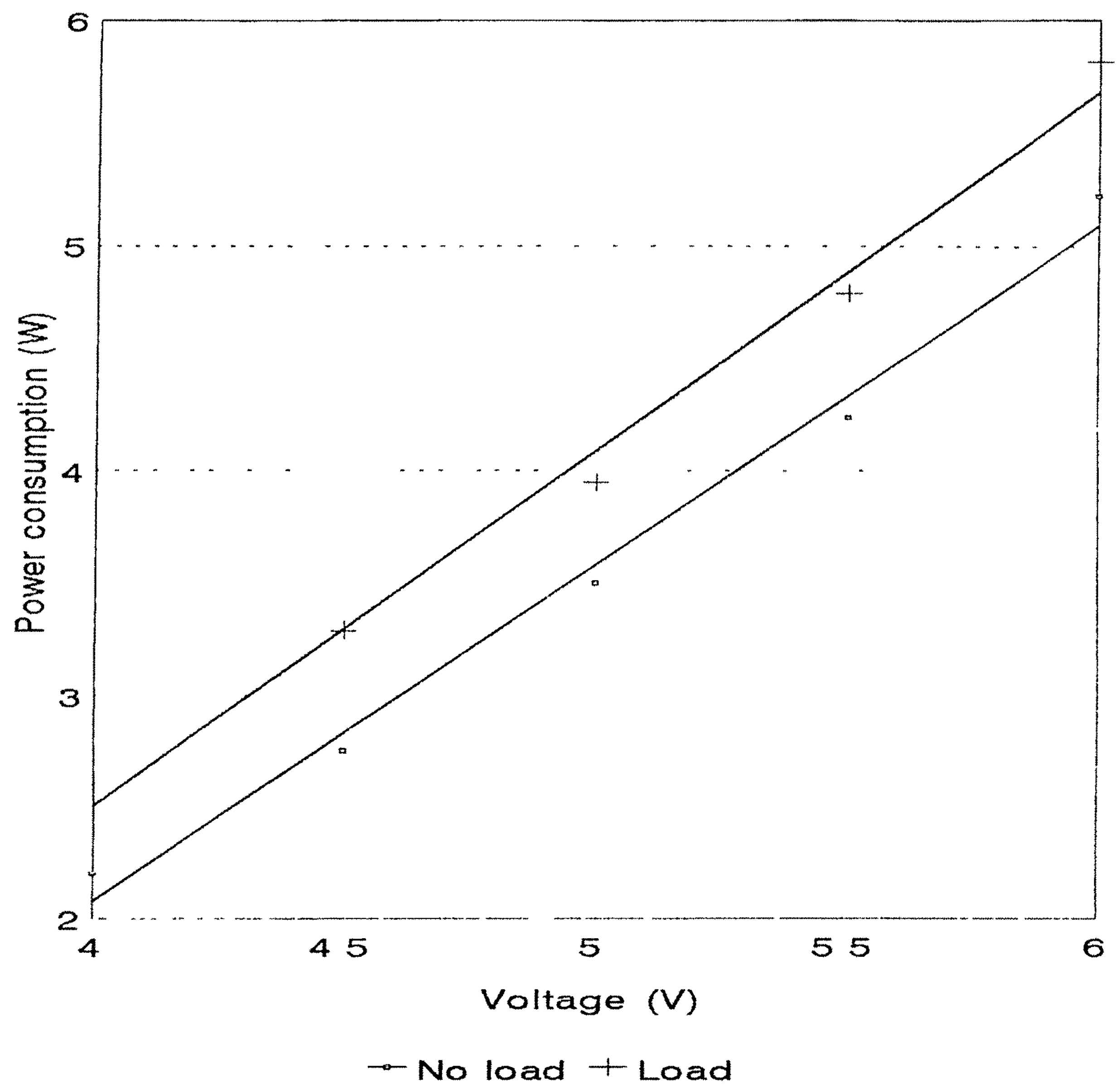


Fig 4.47 Power consumption of prototype spinning disc sprayer

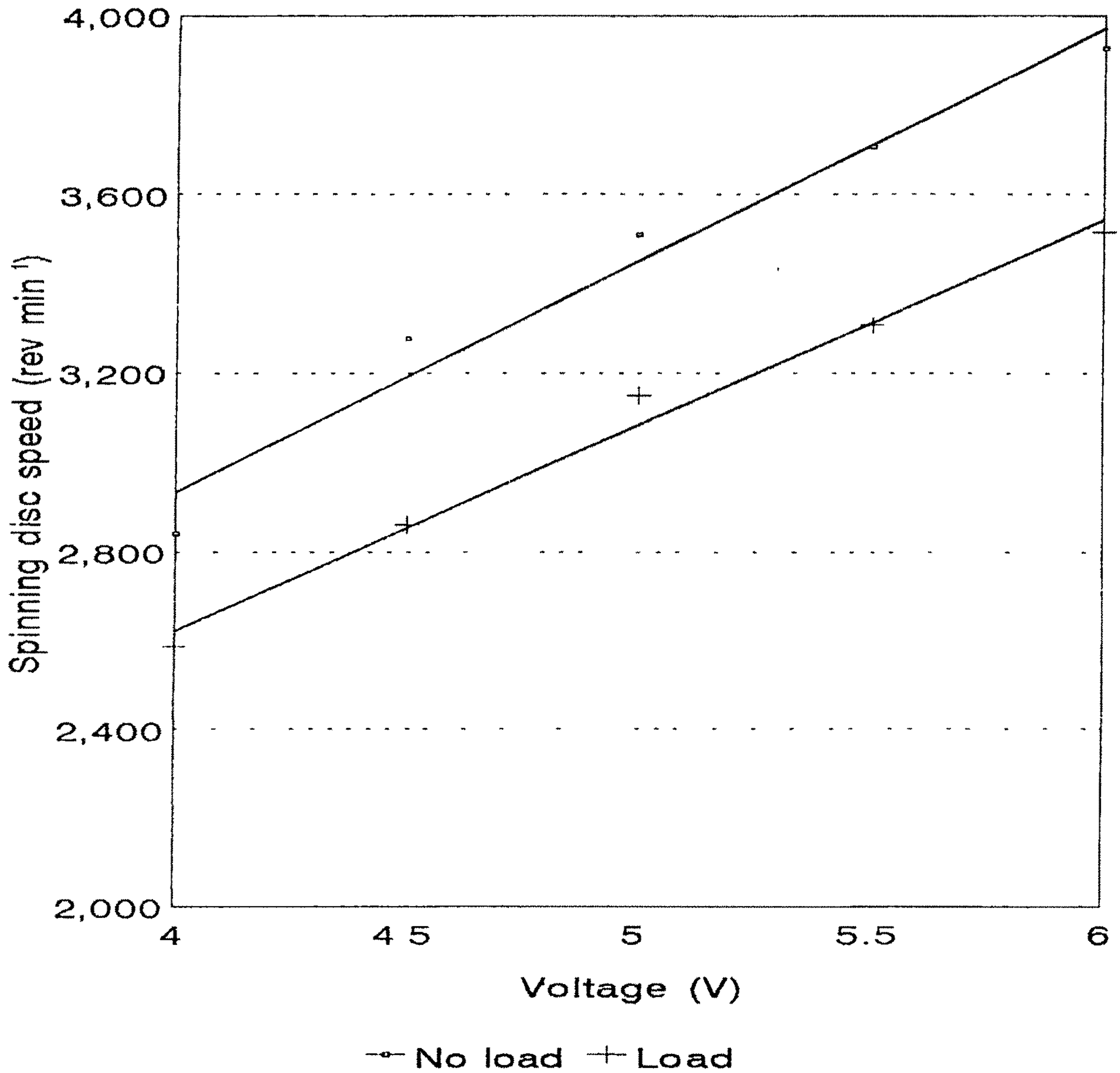


Fig 4.48 Spinning disc speed of prototype sprayer at varying voltage

Table 4.31 Atomization characteristics of prototype spinning disc sprayer

Ambient temperature 30 5°C (db)
Relative humidity 56 0 per cent

Sl no	Spinning disc speed (rev min^{-1})	Horizontal distance from spinning disc centre (mm)								
		600			800			1000		
		VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD	VMD (µm)	NMD (µm)	VMD/NMD
1	2626	260 30	259 80	1 002	285 40	282 65	1 010	332 40	331 50	1 003
2	2994	250 75	255 10	0 983	282 00	279 80	1 008	301 60	301 30	1 001
3	3218	251 70	246 70	1 020	272 50	271 90	1 002	298 00	296 90	1 004
4	3472	242 20	241 30	1 004	270 10	268 60	1 006	289 20	288 40	1 003
5	3578	231 25	227 00	1 019	248 20	246 95	1 006	275 90	275 00	1 003

Both VMD and NMD of spray decreased linearly as the spinning disc speed increased which is in conformity with the results obtained by Matthews (1977) VMD and NMD were close to each other at all the sampling distances from the disc centre However, VMD and NMD increased as the sampling distance increased, Fig 4 49

VMD and NMD of the main satellite spray cloud were 248 20 and 246 95 μm respectively at 800 mm distance from disc centre at the rated 6 V at the full flow rate of 150 cc min^{-1} The sample bromide papers reveal that the distance of spread of the main spray cloud was 800 mm for both the 6 V and 12 V DC motor operated spinning discs at the rated voltages and at full flow rate At full flow rate, for both the DC motors, similar behavioural pattern of decrease in VMD and NMD with increasing disc speed was observed

VMD and NMD of spray varied according to the following regression relations

$$VMD = 293\ 702 - 0\ 0303\ s + 0\ 126\ d \quad (R^2 = 0\ 9345) \qquad (4\ 5)$$

$$NMD = 288\ 584 - 0.0385\ s + 0\ 0132\ d \quad (R^2 = 0\ 9396) \qquad (4\ 6)$$

The effect of replication on VMD and NMD was not significant Effect of spinning disc speed and distance of droplet capture on VMD and NMD were significant at 1 per cent level

Optimum diameter of spray droplets for agricultural operations should be in the range of 200 to 300 μm (Himel and Moore, 1969) VMD of the prototype spinning disc

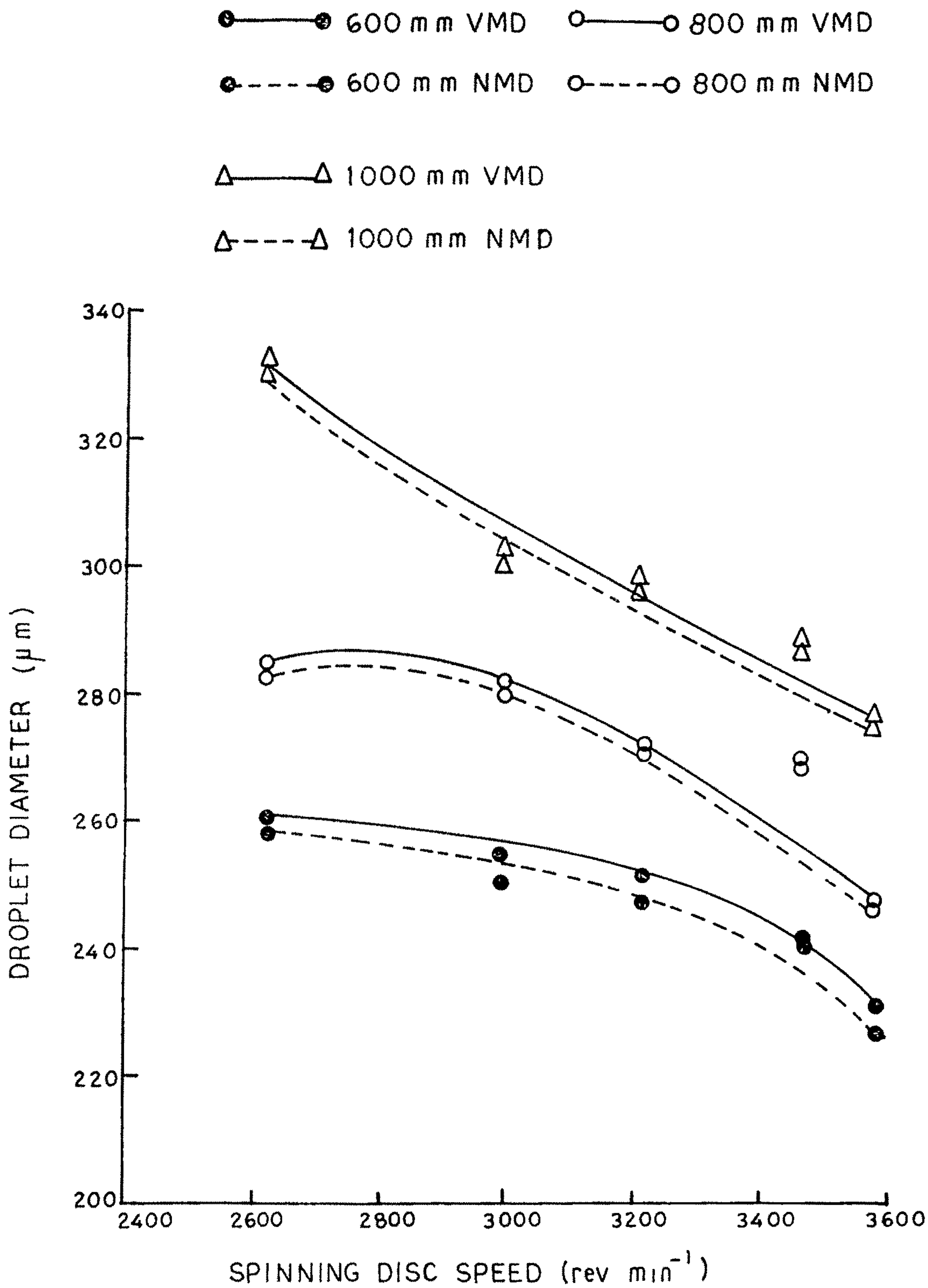


FIG. 4.49 ATOMIZATION CHARACTERISTICS OF PROTOTYPE SPRAYER

sprayer was 231 25 to 285 40 μm at 600 to 800 mm distance from the disc centre This shows the suitability of the sprayer for agricultural applications . VMD : NMD ratio varied from 1 001 to 1 020 which again shows that the sprayer is capable of producing spray droplets of narrower range

Droplet density measurements of the prototype sprayer at different levels of spinning disc speeds and at 600, 800 and 1000 mm distances from the disc centre are given in Table 4 32 In the normal operating range of 3200 to 3580 rev min^{-1} disc speed (5 to 6V), the droplet density varied from 32 to 50 at 600 mm distance and from 25 to 50 at 800 mm distance Johnstone (1973) considered a droplet density of 15 to 20 droplets per square cm would be adequate for controlling most insect pests This conforms the suitability of the sprayer for controlling crop insect pests

As the disc speed increased, droplet density increased at all the sampling distances, Fig 4 50 As the sampling distance increased, droplet density decreased As the disc speed increased, spray droplet size decreased and as a result more droplets were deposited per square cm area Droplet size increased as the sampling distance increased. Due to this, droplet density decreased with increase in disc speed at higher sampling distances

Performance of the 6 V and 12 V DC motor operated spinning discs were compared on wattage basis in terms of VMD and VMD.NMD ratio, Table 4 33. Both the 6 V and 12 V DC motor operated spinning discs behaved closely in terms of VMD, Fig 4 51 The slopes of the VMD curves for 6 V and 12 V discs were the same As the

Table 4.32. Droplet density of prototype spinning disc sprayer

Sl no	Spinning disc speed (rev min^{-1})	Droplet density (No cm^{-2}) Horizontal distance from spinning disc centre (mm)		
		600	800	1000
1	2626	13	10	1
2	2994	14	15	3
3	3218	32	25	5
4	3472	40	40	5
5	3578	50	50	10

Table. 4.33 Performance of spinning discs operated by 6 V and 12 V DC motors

Sl no	6 V motor operated spinning disc			12 V motor operated spinning disc		
	Power (W)	VMD (μm)	VMD/NMD	Power (W)	VMD (μm)	VMD/NMD
1	2 60	285 40	1 010	3 52	270 30	0 992
2	3 29	282.00	1 008	4 14	267 30	1 003
3	3 95	272.50	1 002	4 70	256 50	1 001
4	4 79	270 10	1 006	5 39	246 20	1 001
5	5 82	248 20	1 006	6 12	244 20	1 005

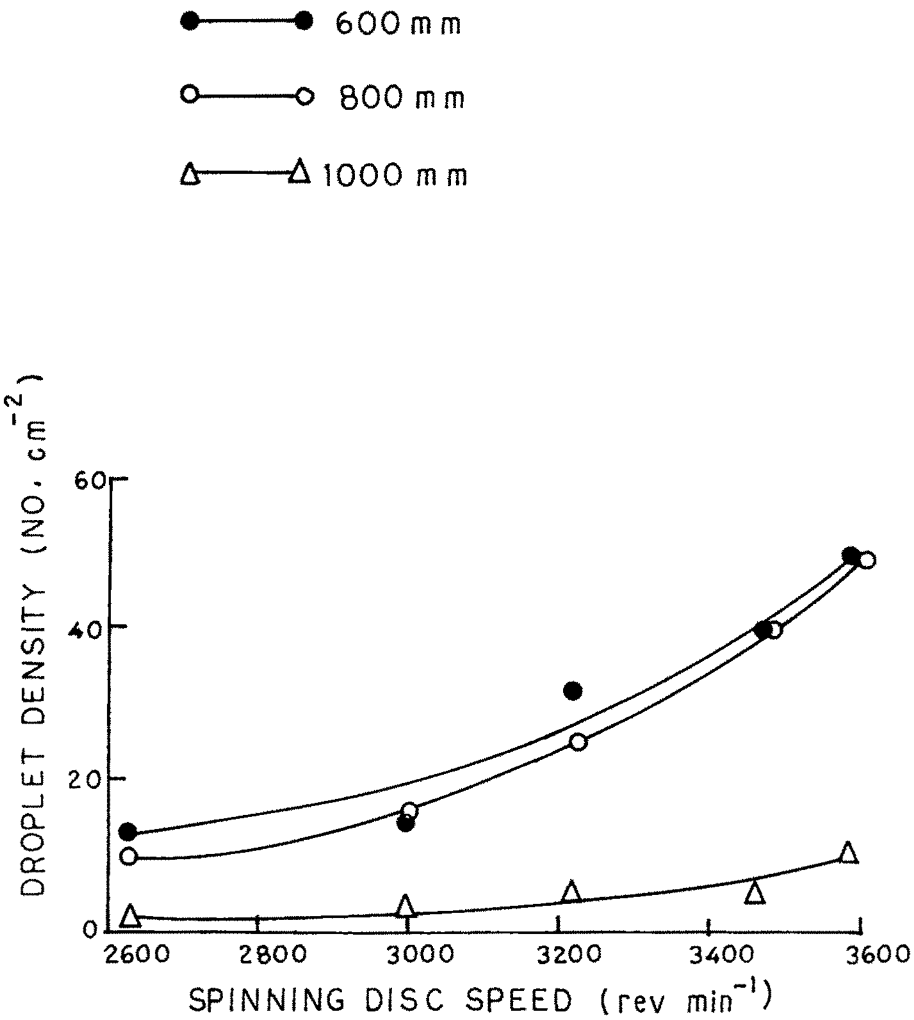


FIG. 4.50 DROPLET DENSITY OF PROTOTYPE SPRAYER

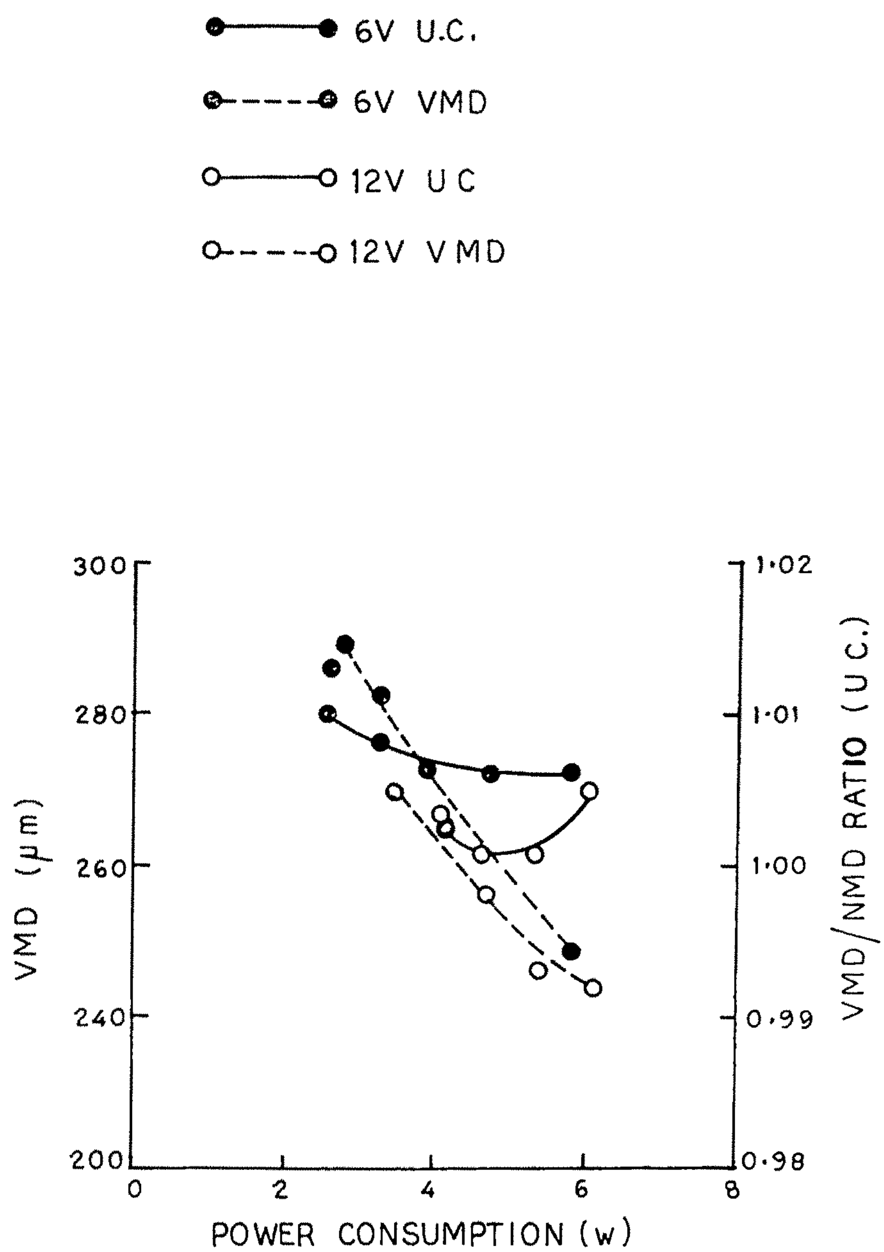


FIG. 4.51 COMPARISON OF 6V AND 12 V DC MOTOR OPERATED SPINNING DISCS

power consumption increased, the uniformity coefficient i.e, the VMD NMD ratio increased in the case of 6 V disc For both the discs, the VMD NMD ratios were within the range of 1 00 to 1 01 This reveals that both the DC motors are capable of producing uniform sized spray droplets

Curvefit analysis of the droplet size distribution of the battery powered sprayers revealed that, in general, the droplet diameter (Y) and the rotational speed of the DC motor (x) were governed by the equation,

$$Y = A + Bx + Cx^2 \qquad (4\ 7)$$

For e g, the mean droplet diameter (Y) and the spinning disc speed (x) in the case of the prototype spinning disc sprayer were inter-related by the following equation,

$$Y = 22\ 87 + 0\ 179\ x - 0\ 338 \times 10^{-4}\ x^2 \quad (R^2 = 0\ 89) \qquad (4\ 8)$$

4.5.3. Energy release pattern of battery

Battery voltage, amperage, power consumption and rotational speed of the DC motor during continuous operation with battery are given in Table 4 34 As the operating time elapsed, battery voltage and power consumption of the motor decreased with a decreasing rate, Fig 4 52. Spinning disc speed decreased with operating time at a constant rate, Fig 4 53. Spinning disc speed of 3423 rev min^{-1} at the beginning of the test reduced to 1826 rev min^{-1} at the end of 6 h of operation. The DC motor ceased to rotate at 8^{th} h of operation The time - voltage curve became asymptotic as the operating time increased

Table 4.34. Energy release pattern of battery for prototype sprayer

Sl no	Operating time (h)	Battery voltage (V)	Current (A)	Power consumption (W)	Spinning disc speed (rev min^{-1})
1	0	6 00	0.57	3 42	3423
2	1	5.10	0 49	2 50	2984
3	2	4 20	0 41	1 72	2512
4	3	3 90	0 36	1 40	2433
5	4	3 70	0 31	1 15	2337
6	5	3.65	0 30	1 10	2091
7	6	3 60	0 30	1 08	1826

4.5.4. Sound level produced

Sound level produced by the prototype spinning disc sprayer in comparison with battery powered pneumatic sprayer and power knapsack sprayer at 0 to 30m distance are given in Table 4 35 At the source of sound emission the prototype spinning disc sprayer produced a sound level of 70 dB(A) battery powered pneumatic sprayer produced 102 dB(A) and power (knapsack) pneumatic sprayer produced 119 dB(A) of sound level Sound level produced by three sprayers reached the constant levels of 43,57 and 68 dB(A) at 30m distance from the source of sound emission, Fig 4 54 The above data show that the spinning disc sprayer is eco-friendly and produces relatively less sound as compared to other sprayers

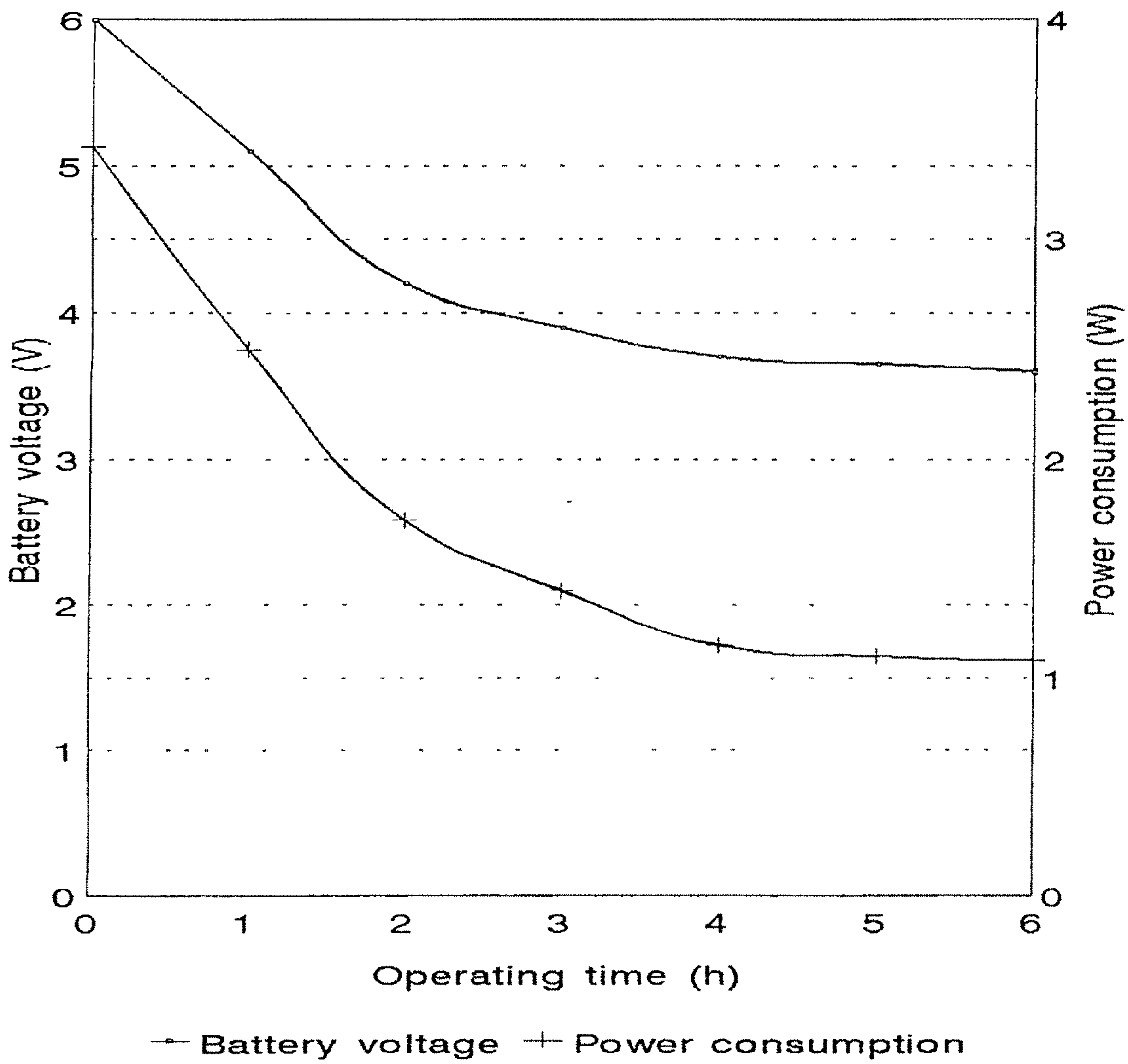


Fig 4.52 Energy release pattern of battery for prototype spinning disc sprayer

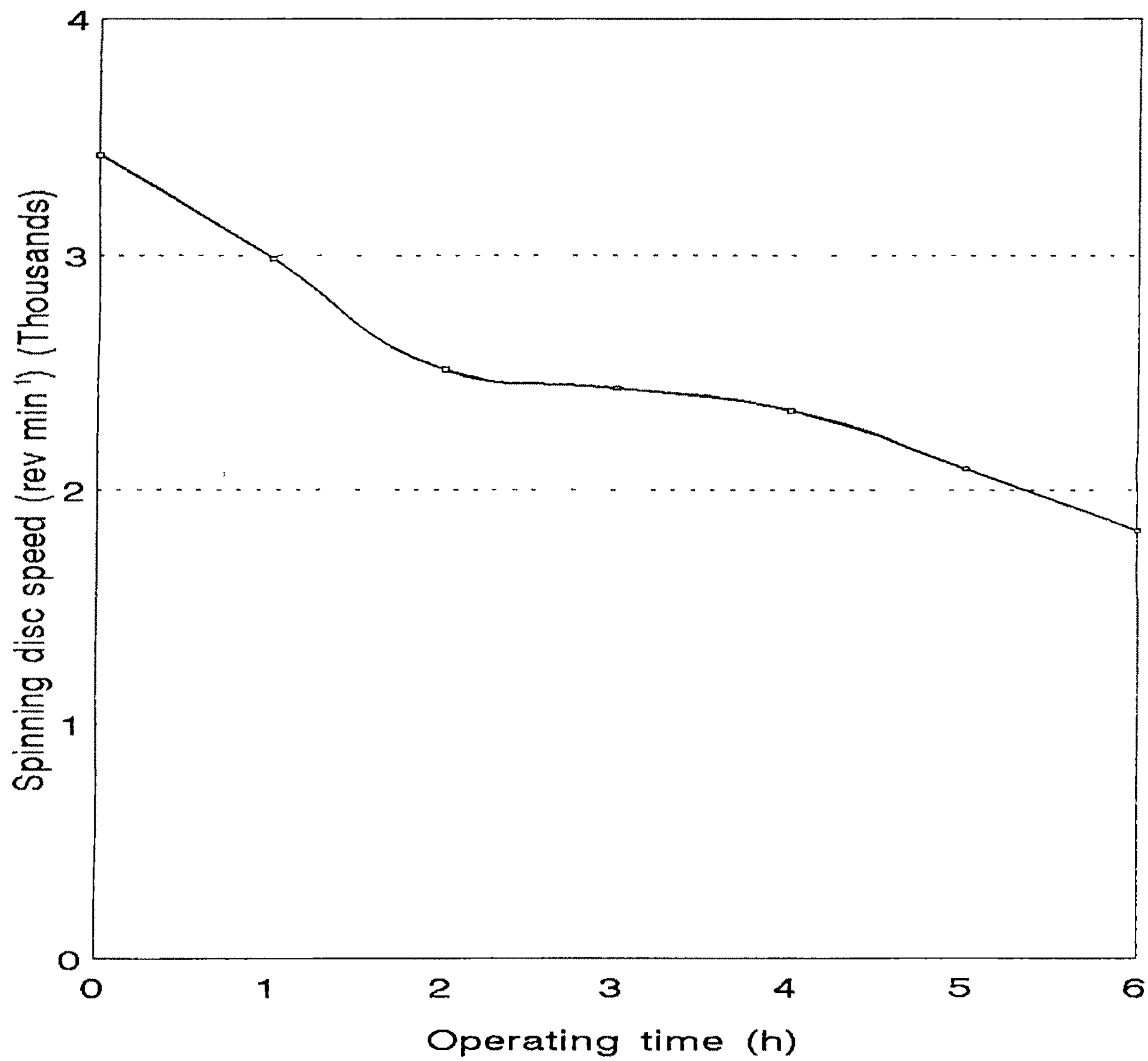


Fig 4.53 Spinning disc speed of prototype sprayer during continuous operation

Table. 4.35. Sound level produced by sprayers

Sl no	Distance from source of sound emission (m)	Sound level produced (dB A)		
		Prototype spinning disc sprayer	Battery powered pnuematic sprayer	Engine powered pneumatic sprayer
1	0	70	102	119
2	1	66	79	104
3	2	63	73	100
4	3	59	69	97
5	4	58	67	95
6	5	58	66	93
7	6	57	65	93
8	7	57	63	91
9	8	56	62	89
10	9	56	62	89
11	10	55	62	88
12	11	54	61	88
13	12	52	61	87
14	13	50	61	87
15	14	49	60	86
16	15	47	60	85
17	16	47	59	85
18	17	45	59	84
19	18	44	59	82
20	19	43	58	81
21	20	43	58	80
22	22	43	58	79
23	24	43	57	75
24	26	43	57	71
25	28	43	57	68
26	30	43	57	68

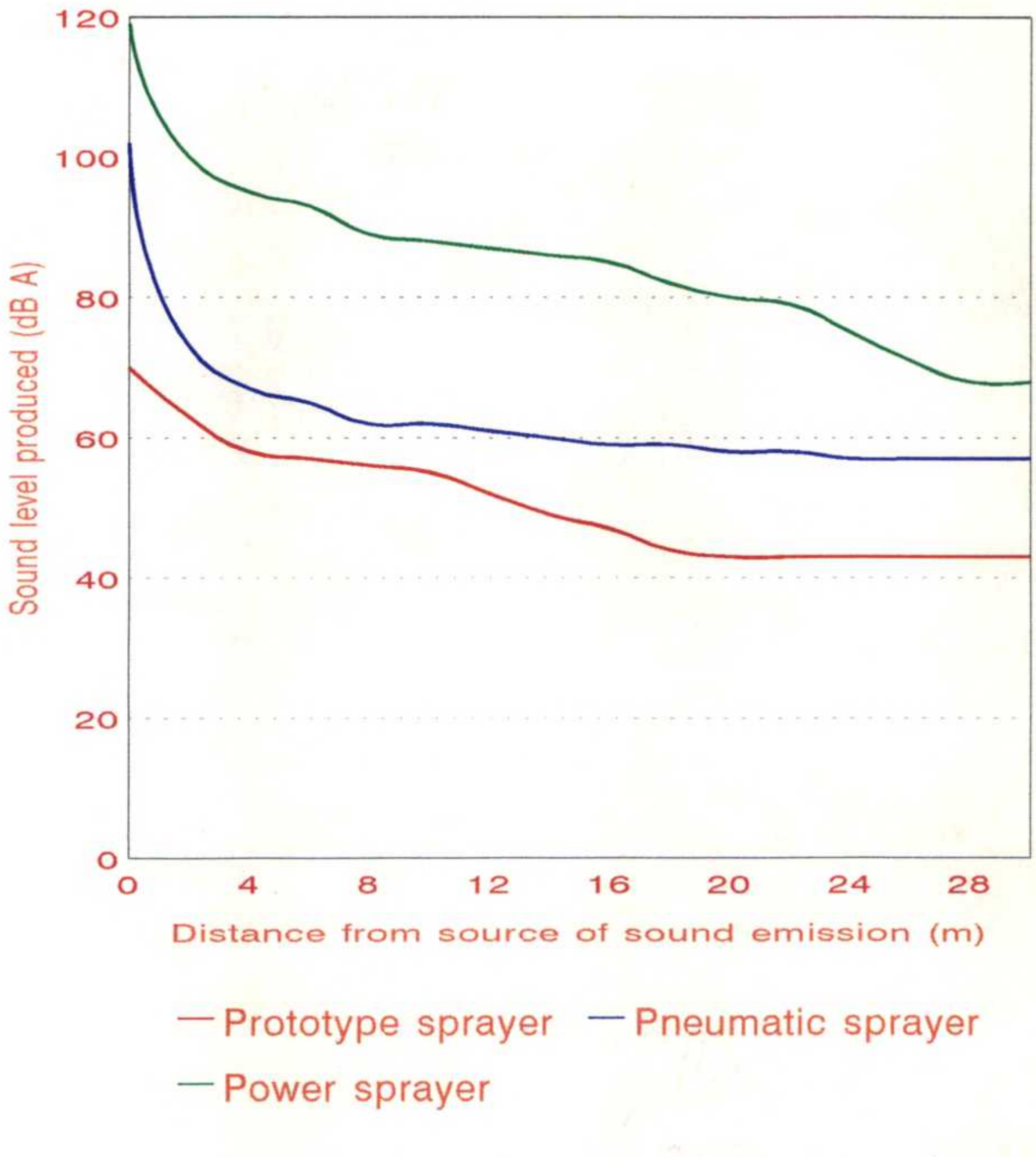


Fig 4.54 Sound level produced by sprayers

4.6. Field performance of the prototype spinning disc sprayer

Results of the field experiment conducted with the battery powered prototype spinning disc sprayer in comparison with two makes of power knapsack sprayer in controlling cotton leaf hopper are presented in Table 4 36 Population of cotton leaf hoppers ranged from 16 4 to 30 6 per leaves before spraying on the crop Among the sprayers evaluated, the prototype spinning disc sprayer consistently registered low insect population ranging from 3 8 to 9.0 per 30 leaves during the period of observation after spraying In the plots sprayed with Aspee power sprayer, the population ranged from 3 4 to 9 4 per 30 leaves In the plots sprayed with Hymatic power sprayer, the population ranged from 5 2 to 12 2 per 30 leaves during the period of observation after spraying

Comparison of treatments revealed the superiority of the spinning disc sprayer (45 litre ha^{-1} spray application rate) with the lowest mean leaf hopper population of 7 84 per 30 leaves where as in the plots sprayed with Aspee and Hymatic power sprayers (150 litre ha^{-1} spray application rate), the population were respectively 11 96 and 11 12 per 30 leaves In the untreated check the mean population was 30 per 30 leaves

All the three sprayers differed significantly from the untreated check The prototype spinning disc sprayer differed significantly from the other sprayers tested for comparison The above results of the field experiment were in agreement with the findings of Johnstone *et al* (1973) and Reed (1977) who have reported that insecticides applied with hand-carried spinning disc sprayers gave similar insect control to that with low volume sprayers

Table. 4.36. Field performance of prototype spinning disc sprayer

Sl no	Period	Mean leaf hopper population in cotton (30 leaves)				
		Treatments				
		T_1	T_2	T_3	T_4	Mean
1	Precount	16 4 (3 98[a])	30 2 (5 47[b])	24 2 (4 81[a])	30 6 (5 42[b])	25 35 (4 92)
2	1 DAT	9 0 (2 60[a])	9 4 (2 99[a])	12 2 (3 35[a])	35 6 (5 96[a])	16 55 (3 73)
3	4 DAT	5 2 (2 10[a])	8 6 (2 86[a])	7 0 (2 59[a])	38 0 (6 10[b])	14 70 (3 41)
4	7 DAT	3 8 (1 90[a])	3 4 (1 79[a])	5 2 (2 17[a])	25 4 (4 94[b])	9 45 (2 70)
5	14 DAT	4 8 (2 07[a])	8 2 (2 81[a])	7 2 (2 59[a])	20 8 (4 43[b])	12 50 (2 98)
	Mean	7 84 (2.53[a])	11 96 (3 18[b])	11 12 (3 10[a])	30 08 (5 37[c])	15 25 (4 05)

Figures in parenthens are square root transformed values

In a horizontal column means followed by a common letter are not significantly (statisfically) different

DAT-days after treatment

Biological efficiency of the prototype spinning disc sprayer was 87 63 per cent in comparison with 61.09 and 72 62 per cent for the two makes of power knapsack sprayers in the same field and for the same crop

4.7. Cost - economics of the prototype spinning disc sprayer

Fixed cost and variable cost of the prototype spinning disc sprayer were Rs 6 25 ha^{-1} and Rs 56 50 ha^{-1} as compared to Rs 9 50 ha^{-1} and Rs 63 75 ha^{-1} for power knapsack sprayer which is the commonly used low volume sprayer in Indian villages for plant protection Operational cost of the spinning disc sprayer (excluding the cost of chemical) was found to be Rs 62 75 ha^{-1} in comparison with Rs 73 25 ha^{-1} for power sprayer, Table 4 37 Fig 4.55 depicts the performance of the prototype spinning disc sprayer in terms of biological efficacy and operational cost in comparison with power sprayer

Table 4.37. Performance of prototype spinning disc sprayer

Sl no	Sprayer	Effective field capacity	Biological efficacy	Sound level produced	Operational cost ($Rs\ ha^{-1}$)			Initial cost
		($ha\ h^{-1}$)	(%)	(dB A)	FC	VC	Total	(Rs)
1	Prototype spinning disc sprayer	0 25	87 63	70	6 25	56 50	62 75	1350
2	Power knapsack sprayer	0 35	72 62	119	9 50	63 75	73 25	4500

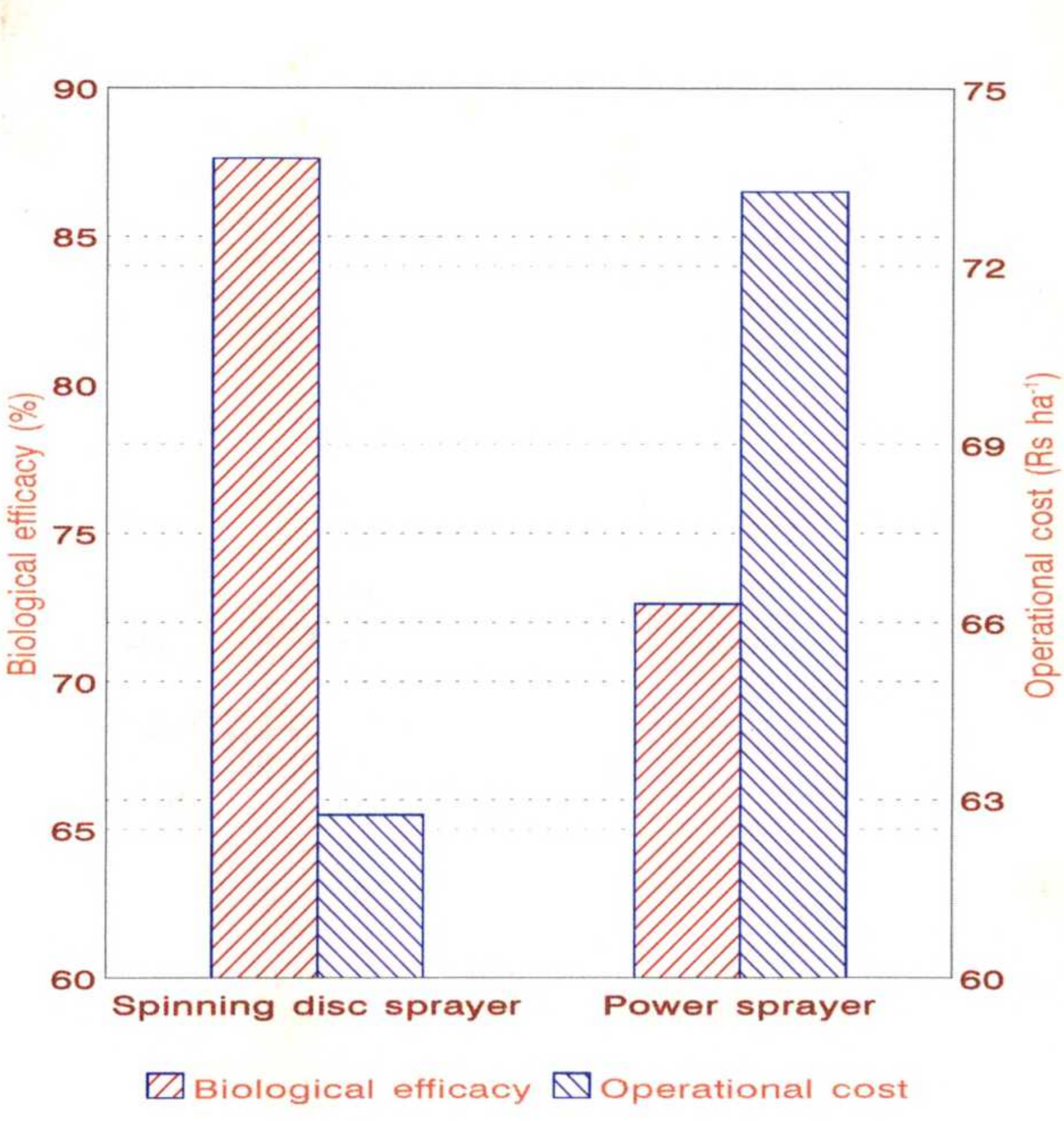


Fig 4.55 Performance of prototype spinning disc sprayer

SUMMARY AND CONCLUSIONS

CHAPTER V

SUMMARY AND CONCLUSIONS

Plant protection is one of the important operations in crop production The annual expenditure to operate the engine powered plant protection machinery in India will be around Rs 27,000 million by 2000 AD This investigation was undertaken with an objective to reduce the above expenditure by developing a battery powered sprayer Experiments were conducted to study the effect of operational and atomizer parameters on spray distribution pattern and atomization characteristics of battery powered hydraulic, pneumatic and centrifugal spraying systems A prototype spinning disc sprayer was developed based on the results of the investigation and the field performance of the prototype sprayer was evaluated The summary and conclusions drawn are given below

1 A spray patternator was developed as specified by the Bureau of Indian Standards to study the spray distribution pattern of the spraying systems The spray patternator could give uniform and consistent readings

2 A mean spread factor of 0.645 was determined for the methylene blue dye on glazed bromide paper as droplet sampling surface, using a narrow spectrum droplet generator for finding the spray droplet diameter of the spraying systems

3. A maximum power of 53 2 W was consumed by the hydraulic spraying system with 1390 rev min^{-1} speed of gear pump at the rated 12 V For operating the gear pump, 12 5 W power was expended by the system and for liquid pumping alone 26 7 W power was expended at the rated voltage. The mean rate of increase in power consumption per unit increase in voltage for the system was 6 9 W

4 CV for the spray volume distribution across the spray swath for the system with hollow cone nozzle varied from 99 8 to 74 1 per cent as the liquid pressure increased from 44 to 113 kPa This indicated the unacceptability of the spray distribution of the hydraulic spraying system

5 There is little scope to bring down the CV and improve the uniformity of spray distribution for the system by increasing the liquid pressure beyond 113 kPa

6 Liquid pressure, flow rate and spray angle of the system with hollow cone nozzle were 112 8 kPa, 310 cc min^{-1} and 74 90 deg respectively at the rated voltage whereas the rated pressure, flow rate and spray angle of the nozzle are 276 kPa, 473 cc min^{-1} and 75 deg respectively.

7 VMD of the system with hollow cone nozzle varied from 307 to 242 μm and the NMD varied from 256 to 219 μm as the liquid pressure increased from 44 to 113 kPa The uniformity coefficient of droplet size distribution (VMD NMD ratio) varied from 1 11 to 1 14 in the above pressure range

8. For operating the hydraulic spraying system, the effective service time of battery per cycle was 30 min.

9. The maximum power consumption of the pneumatic spraying system was 63 W at the rated voltage. The mean rate of increase in power consumption per unit increase in voltage for the above system was 3.7 W

10 CV of the spray distribution for the system varied from 54.1 to 45.6 per cent as the air velocity increased from 4.1 to 5.6 ms^{-1}

11 There is scope to bring down the CV and improve the spray distribution by increasing the air velocity beyond 5.6 ms^{-1}

12 VMD of the system with 80 cc min^{-1} flow rate varied from 349 to 202 μm and the NMD varied from 274 to 165 μm at 800 mm distance from the nozzle as the air velocity increased from 4.1 to 5.6 ms^{-1} Correspondingly the VMD NMD ratio ranged from 1.23 to 1.36

13 For operating the pneumatic spraying system, the effective service time of battery per cycle was 60 min

14 With straight grooved spinning disc, 11.7 per cent of CV was obtained at the rated 12 V and full fluid flow rate of 150 cc min^{-1} The corresponding CV with inclined grooved spinning disc was 16.4 per cent

15. Power consumption of straight grooved spinning disc was 8.9 per cent lesser to that of inclined grooved disc with full fluid flow rate at the rated voltage.

16. The droplets produced by straight grooved spinning disc were smaller to inclined grooved spinning disc at all the flow rates and sampling distances at the rated voltage

17 VMD · NMD ratio for the straight grooved spinning disc ranged from 1 02 to 1 08 whereas that for inclined grooved disc ranged from 1 03 to 1 09 at 150 cc min^{-1} flow rate at all the sampling distances of 200 to 1000 mm That is, the uniformity of dropsize distribution was better with straight grooved disc

18 Maximum power consumption of the centrifugal spraying system at the rated 12 V was 6 1 W The mean rate of increase in power consumption per unit increase in voltage for the above system was 0 63 W

19 VMD of the system with 150 cc min^{-1} flow rate varied from 270 to 244 μm and NMD varied from 277 to 243 μm as the spinning disc speed increased from 2725 to 4275 rev min^{-1} NMD VMD ratio varied from 0 99 to 1 01

20 For operating the centrifugal spraying system, the effective service time of battery per cycle was 8 h.

21. Among the battery powered hydraulic, pneumatic and centrifugal spraying systems, centrifugal spraying system performed better in terms of minimum power consumption, minimum CV, more uniformity of dropsize distribution and maximum effective service time of battery per cycle.

22 Maximum power consumption of the prototype spinning disc sprayer was 5 82 W at the rated voltage For atomizing the spray liquid alone 0 6 W power was expended by 6 V DC motor operated spinning disc whereas 0 84 W power was expended by 12 V DC motor operated spinning disc Ninety per cent of the power was consumed to rotate the spinning disc and only 10 per cent power was consumed for breaking the spray liquid into droplets

23 VMD of the prototype spinning disc sprayer varied from 285 to 248 μm and the NMD varied from 283 to 247 μm as the spinning disc speed increased from 2625 to 3580 rev min^{-1} Uniformity coefficient of dropsize distribution varied from 1 002 to 1 010

24. Performance of the spinning disc when operated by 6 V and 12 V DC motors was similar interms of VMD and uniformity of dropsize distribution The prototype spinning disc sprayer could be effectively operated by battery for a duration of 6 h

25 The prototype spinning disc sprayer produced a sound level of 70 dB(A) as compared to 119 dB(A) by power knapsack sprayer at the source of sound emission.

26 Biological efficacy of the prototype spinning disc sprayer in controlling cotton leaf hopper was 87 6 per cent as compared to 72.6 per cent for the power sprayer

27 Operational cost of the prototype spinning disc sprayer was Rs 63 ha^{-1} in comparison with Rs 74 ha^{-1} for power sprayer

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* original not seen

APPENDIX A

MODEL COMPUTATION OF VMD AND NMD

VMD, NMD FN4PEACH

HEIGHT FROM THE SURFACE 50 CM & SWATH 3 CM TOWARDS THE r

THE VALUES GIVEN BELOW ARE THE FED DATA (i.e.) THE VALUE RE-

CONSIDER ONLY 50 NUMBER OF DATA

23.000	24.000	24.000	24.000	24.000
24.000	24.000	24.000	24.000	24.000
24.000	24.000	24.000	25.000	25.000
25.000	25.000	25.000	25.000	25.000
25.000	25.000	25.000	25.000	25.000
25.000	26.000	26.000	26.000	26.000
26.000	26.000	26.000	26.000	26.000
27.000	27.000	27.000	27.000	27.000
27.000	27.000	27.000	27.000	28.000
28.000	28.000	29.000	31.000	32.000
0.000	0.000	0.000	0.000	0.000

THE CORRECTION FACTOR IS 0.0450

THE MAGNIFICATION FACTOR IS 17.60

THE VALUES GIVEN BELOW ARE ONE IN WHICH THE CORRECTION FACTOR HAS BEEN INCORPORATED

261.096	272.448	272.448	272.448	272.448
272.448	272.448	272.448	272.448	272.448
272.448	272.448	272.448	283.800	283.800
283.800	283.800	283.800	293.900	283.200
283.800	283.800	283.800	283.800	283.800
283.800	295.152	295.152	295.152	295.152
295.152	295.152	295.152	295.152	295.152
306.504	306.504	306.504	306.504	306.504
306.504	306.504	306.504	306.504	317.856
317.856	317.856	329.208	351.912	363.264
0.000	0.000	0.000	0.000	0.000

CLASS INTERVAL	FREQUENCY (N)	PERCENT OF CUMULATIVE FREQUENCY	PROBIT SN (Y1)	MEAN DIA. (D)	LOG(D) (X)
260 - 285	26.00	52.00	5.05	277.69	2.44
285 - 310	18.00	88.00	6.18	300.83	2.48
310 - 335	4.00	96.00	6.75	320.69	2.51
335 - 360	1.00	98.00	7.05	351.91	2.55
360 - 385	1.00	100.00	0.00	363.27	2.56

CLASS INTERVAL	CUMULATIVE OF D**3*N	PERCENT OF D**3*N	PROBIT (Y2)	LOG(D) (X)
260 - 285	0.5567257	44.00	4.85	2.444
285 - 310	1.0467608	82.00	5.92	2.479
310 - 335	1.1786875	93.00	6.48	2.506
335 - 360	1.2222689	96.00	6.75	2.546
360 - 385	1.2702062	100.00	0.00	2.560

The VMD is , 274.8850

The NMD is , 268.1676

The ratio between VMD to NMD is, 1.025049

APPENDIX B

ANALYSIS OF VARIANCE FOR FIELD EXPERIMENT RESULTS

Source	DF	SS	MS	F
P	4	59 53	14 88	18 48
T	3	117 17	39 06	48 49
P x T	12	23 81	1.98	2 46
Error	80	64 43	0 81	
Total	99	264 94		

Source	SE	SEd	CD
P	0.20	0 28	0 56
T	0 18	0 25	0 51
P x T	0 40	0 57	1 13

P - Penod
T - Treatment

APPENDIX C

DETERMINATION OF OPERATIONAL COST

Depreciation cost

$$D = \frac{P - S}{L}$$

where	D	=	annual depreciation cost		
	P	=	purchase price	=	Rs 1350 for prototype sprayer and Rs 4500 for power sprayer
	S	=	salvage value	=	5 per cent of purchase price
and	L	=	useful life of sprayer	=	2000 h in 8 yrs

Interest on investment

$$I = \frac{P+S}{2} \times \frac{i}{100}$$

where I = annual interest charge

and i = interest rate = 14 per cent

Repairs and maintenance charges

$$TAR = 0\ 159\ x^{1\ 4}$$

where TAR = total accumulated repair cost divided by purchase price, per cent

and x = accumulated hours of use divided by wear out life, per cent

Fuel and oil costs

Specific fuel consumption rate of 1 25 kW petrol engine for the power sprayer	= 0 25 litre / kW h

Oil consumption rate = 3 per cent of fuel consumption on volume basis

Cost of petrol	= Rs 20/litre
Cost of oil	= Rs 63 /litre

Operators' wages

One operator + One helper

Wages for operator (man)	= Rs 39 60/day of 8h
Wages for helper (woman)	= Rs 35 20/day of 8h

APPENDIX - D

PUBLICATIONS RELATED TO THE THESIS

GENERAL

DEVELOPMENT OF A BATTERY OPERATED LOW VOLUME KNAPSACK SPRAYER

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Spraying chemicals on agricultural crops is usually done either by power knapsack sprayers or manually operated sprayers in the developing countries. The power sprayer is costly and its operational cost is also high with frequent repairs. Manual sprayers require more water and have poor field coverage. Therefore, a battery operated low volume knapsack sprayer has been developed to overcome the above problems

The battery operated low volume sprayer consists of a 10 litre plastic tank and a 6-volts rechargeable battery both fixed in a frame which is carried on the back of the operator The chemical is taken from the tank to a dripping nozzle. A cut-off valve is provided in the hose line to stop the flow of spray liquid when desired A plastic disk is rotated at a speed of 3500 revolutions/minute by a direct current micro-motor. The liquid drops falling from the nozzle on the rotating disc are broken to fine droplets, Fig 1

The sprayer weighs only 7 kg without liquid The field coverage of the sprayer is 0 20 ha/hour. It needs only about 50 litres/ha Recharging of the battery can be done by the farmers at home The battery recharged during the night can be used for 8 hours of operation during the day The sprayer is suitable for crops like groundnut, pulses, cotton and vegetables The sprayer is capable of producing smaller sized droplets of about 150 micrometers mean diameter than what the other sprayers produce The characteristics facilitate complete coverage of the crop canopy by the chemicals Field test conducted on cotton (MCU 11) with the battery sprayer in comparison with two makes of power knapsack sprayers (mist blowers) by spraying methyl demeton @ 187 5 g ai/ha for the control of leaf hopper, *Empoasca devastens*, revealed that the battery sprayer excells the other sprayer in controlling the crop insect pest The per hectare cost of spraying works out to Rs 25.0 whereas the cost of spraying with power and manual sprayers are Rs 35 0 and Rs 45 0 per hectare respectively, excluding the cost of chemicals The battery operated low volume sprayer costs around Rs 1000 0

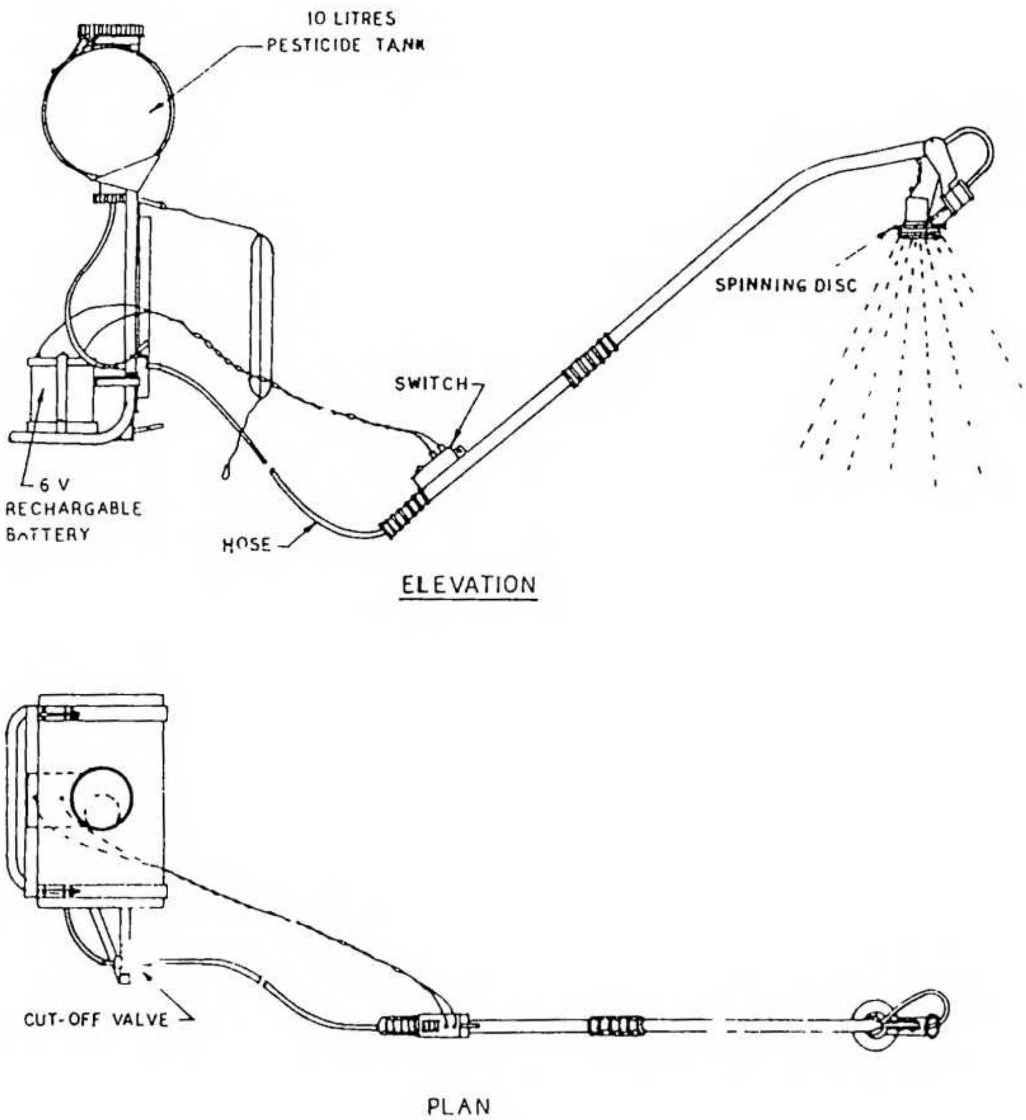

FIG 1 LOW VOLUME' KNAPSACK SPINNING DISC SPRAYER

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Evaluation of a low volume knapsack spinning disc sprayer

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ABSTRACT

A low volume knapsack battery powered spinning disc sprayer was developed Tests were carried out to determine the average application rate and to find the effect of operating time on battery voltage, micro-motor speed, numerical median diameter and volume median diameter of the spray spectrum Droplets produced by the sprayer were of uniform size throughout the operation. Operational cost of the sprayer was Rs 25/ha compared to Rs 34/ha and Rs 45/ha for power knapsack sprayer and manual sprayers, respectively

Spraying chemicals on agricultural crops are done by power sprayers and manual sprayers The power sprayer is costly and has maintenance problems. Manual spraying require large amount of water which puts considerable hardship on farmers. Ultra Low Volume (ULV) spinning disc sprayer has not become popular in our country. The operator has to carry the load of pesticide in his hand throughout the field operation in the ULV sprayer (Tajuddin 1991).

Awadhwal and Takenaga (1989) developed and tested a knapsack twin spinning disc sprayer. A 1 5 m wide boom is located at the rear of the operator. The sprayer required 15 litre of water and 1.5 man-h/ha. Field capacity of the sprayer was 0.66 ha/h.

By 2000 A.D. India alone will be in need of 8 million power sprayers and dusters of 1.5 kW engine. The energy demand of these machines has to be brought down. Hence, a low volume knapsack spinning disc sprayer powered by a 6 volt battery has been developed and tested.

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MATERIALS AND METHODS

Initially two models, viz double and triple spinning disc sprayers were developed Two spinning discs were fixed 1500 mm apart in a T-shaped handle made of 18 mm x 10 mm x 3 mm aluminium angle section The spray fluid was taken from a 10 litre plastic tank to the spinning discs by a plastic hose through cut-off valves. The triple spinning disc sprayer was made by replacing the T-shaped handle with a 5 m long bamboo pole (two poles jointed together) on which three micro-motors with spinning discs were fixed (Tajuddin *et al* 1991). The double spinning disc sprayer had the manoevrability problems. The triple spinning disc sprayer requires two operators. Therefore both these sprayers were not accepted by the farmers. Based on the feed back, a third model was developed (Fig 1 and Fig 2), the specifications are given below.

Power source	:	6 volt rechargeable lead acid battery
Pesticide tank capacity	:	10 litres
Dry weight	:	7 kg

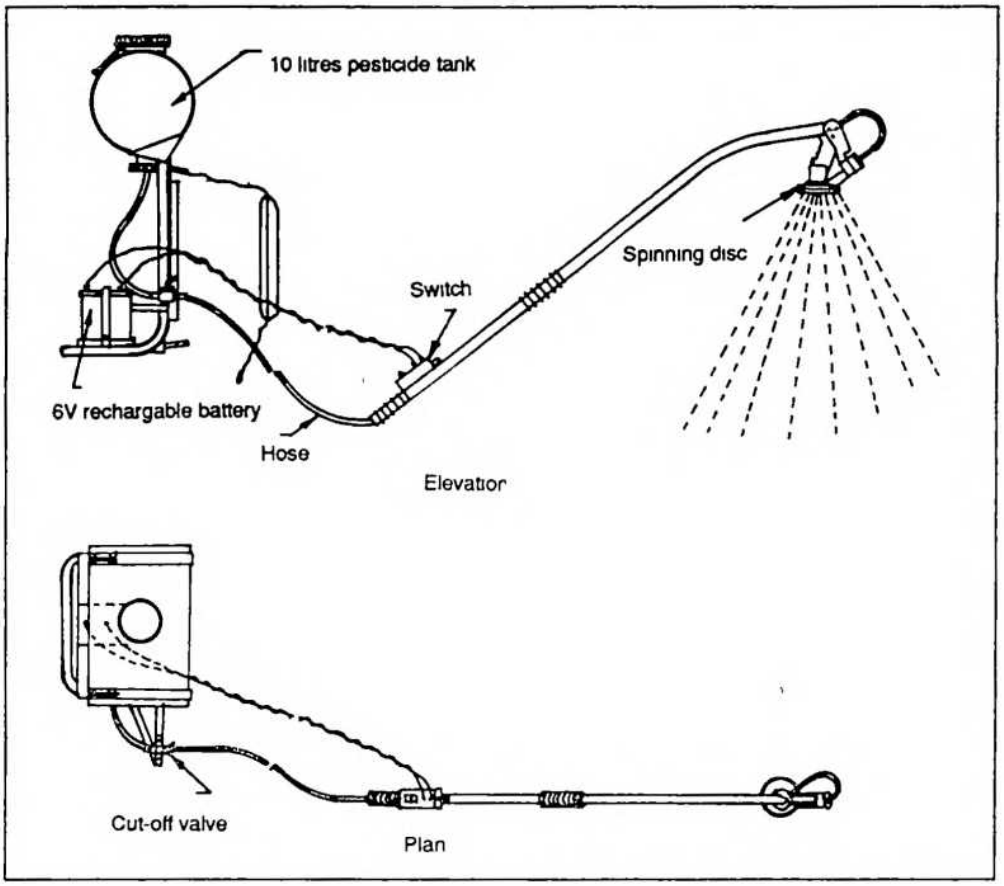

Fig 1 Low volume knapsack spinning disc sprayer

Mean application rate	50 litres/ha
Field coverage	0 20 ha/h

The recommended flow rate of commercial ULV spinning disc is 3 6 litre/h The flow rate has been increased suitably to have low volume spray

Laboratory tests were conducted to determine the average flow rate through the spinning disc 'Heli Spray' by measuring the time taken for the discharge of one litre of water at the full tank volume A test was also conducted to study the variation in battery voltage, micro-motor speed, numerical median diameter (NMD) and volume median diameter (VMD) of the spray spectrum with respect to the operating time The sprayer was operated under load with a fully charged battery continuously until the micro-motor ceased to rotate

After every 2 hours of operation, battery voltage and micro-motor speed were measured and the spray droplets were collected on magnesium oxide coated glass slides placed in the same location throughout the test, i e 100 mm horizontal distance and 500 mm vertical distance from the disc periphery Battery voltage and amperage of the micro-motor were measured by a AC-DC multimeter Micro-motor speed was measured by a contactless

Fig 2 Low volume knapsack spinning disc sprayer in field operation

digital tachometer. A minimum of 10 tachometer readings were taken for each test. NMD and VMD of each spray spectrum were determined using the standard procedure described by Mathews (1979) and Regupathy and Dhamu (1990). After allowing complete spreading of impinged droplets on the slides for 24 hours, the inner diameter of craters formed were measured using biological microscope provided with ocular and stage micrometers. The true droplet size was determined by using the spread factor of 0.86.

RESULTS AND DISCUSSION

Average flow rate through the spinning disc was 9.47 litres/h (Table 1). For an effective field capacity of 0.20 ha/h, average application rate by this sprayer was determined as 47.37 litres/ha.

Battery voltage decreased with the elapse of operating time (Fig 3). The time voltage curve became more or less asymptotic at 3.6V. Micro-motor speed decreased with operating time (Fig 4). The 3423 rev/min speed at the beginning of the test reduced to 1826 rev/min at the end of 6 h operation. The micro-motor ceased to rotate at eighth hour of operating time.

Table 1 Determination of average spray application rate of the low volume knapsack spinning disc sprayer

Time taken for discharge of one litre (s)	Flow rate (litre/h)
410	8.78
390	9.23
400	9.00
384	9.38
350	10.29
354	10.17
380	9.47

Average flow rate : 9.47 litre/h

Average spray application rate for the effective field capacity of 0.20 ha/h = 47.37 litre/ha

Table 2 Effect of operating time on battery voltage, amperage, micro-motor speed, NMD and VMD of the knapsack spinning disc sprayer

Operating time (h)	Battery voltage (v)	Amperage (A)	Micro-motor speed (rev/min)	VMD (µm)	NMD (µm)	VMD/NMD
0	5 95	0 57	3423	124 30	117 36	1 06
2	4 20	0 41	2512	154 71	139 47	1 11
4	3 70	0 31	2337	163 87	152 93	1 07
6	3 60	0 30	1826	185 99	175 59	1 06

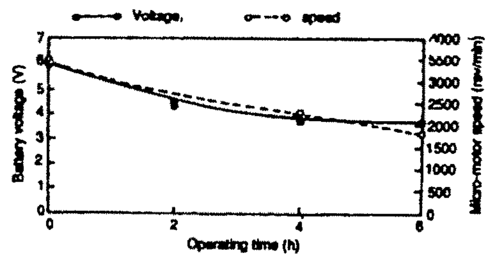

Fig 3 Effect of operating time on battery voltage and micro-motor speed

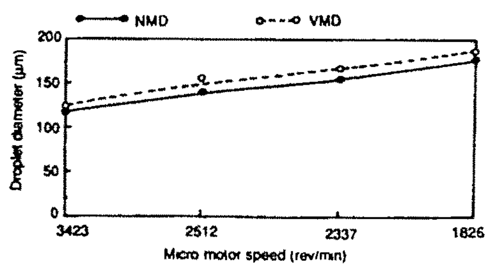

Fig 4 Effect of micro-motor speed on NMD and VMD

Both NMD and VMD of the sprayer increased more or less linearly from 120 to 175 µm and from 125 to 180 µm respectively when the micro-motor speed decreased from 3423 to 1826 rev/min. VMD/NMD ratio was in the range of 1.06 to 1.11 throughout the test which showed that the sprayer could produce uniform sized droplets irrespective of micro-motor speed (Table 2) Multilinear regression analysis of the data revealed that the operating time had high significant effect (having a F value of 38.33) on battery voltage, micro-motor speed, NMD and VMD

Field tests conducted with the low volume knapsack spinning disc sprayer in comparison with power knapsack sprayer on MCU 11 cotton crop in controlling leaf hopper, *Empoasca devastens* by spraying methyl demeton @ 187 5 g ai/ha revealed that the biological efficacy of the low volume spinning disc sprayer was better than the power sprayer

The initial cost of the low volume knapsack spinning disc sprayer was Rs 980/- Operational cost of the sprayer was Rs 25/ha excluding the cost of chemicals in comparison with Rs 34/ha for power knapsack sprayer and Rs 45/ha for manual sprayers

The low volume knapsack spinning disc sprayer requires about 50 litres of water to cover one ha Initial cost of the sprayer is less than the power sprayer The limitation of the sprayer is that the crop height should be below the liquid level in the pesticide tank

ACKNOWLEDGEMENTS

Financial assistance of the Indian Council of Agricultural Research, New Delhi, for developing the prototype sprayers is gratefully acknowledged Author is grateful to Er M Sankaranarayanan, System Analyst, for analysing the results statistically

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AGRICULTURE

The low-volume sprayer hitchhikes on the farmer's back. Powered by a rechargeable battery, the equipment makes economic sense for a small farmer.

Knapsack sprayer for small farmers

A BATTERY-POWERED low volume knapsack sprayer has been developed to overcome the drawbacks of powered sprayers (high investment and operational cost) and manually operated ones (poor field coverage and wastage of water).

The low-volume sprayer consists of a 10 litre plastic tank and a six volts rechargeable battery, both fixed in a frame which is strapped on to the back by the operator. The chemical is drawn from the tank into a dripping nozzle. A cut-off valve is provided in the hoseline to stop the spray when desired. A plastic disc is mounted at the pipe-end and rotated at a speed of 3,500 revolutions per minute by a direct current micro-motor. The liquid drops falling from the nozzle on the rotating disc are broken into fine droplets.

The knapsack sprayer weighs seven kilograms net. The field coverage of the sprayer is 0.20 hectares per hour. It needs about 50 litres of water per hectare. Farmers can recharge the battery during night and use it for eight hours during the day.

The sprayer is suitable for crops such as groundnut, pulses, cotton and vegetables. Per-hectare-cost of spraying worked out to Rs. 25 whereas the cost of spraying by power sprayer and manual sprayers are around Rs. 35 and Rs. 45 per hectare, which excludes the cost of chemicals. The battery powered sprayer costs around Rs. 1,000

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PERFORMANCE EVALUATION OF A LOW VOLUME KNAPSACK SPINNING DISC SPRAYER ON COTTON

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ABSTRACT

A battery powered low volume knapsack spinning disc sprayer was developed Laboratory tests were conducted to determine the average spray application rate, numerical median diameter and volume median diameter of the sprayer developed The sprayer was evaluated on cotton to control leaf hopper in comparison with two makes of power knapsack sprayers The replicated test results revealed that the spinning disc sprayer could control more number of the crop insect pests than the other sprayers taken for comparison

INTRODUCTION

Hand carried spinnings disc controlled droplet application (c d a) sprayers have been successfully used to apply several standard wettable powders and emulsifiable concentrate (e c) formulation diluted in water for the control of weeds, insect pests and diseases of many crops (Attique and Shakeel, 1983,). Many devices have been developed to produce a narrower range of droplets than that produced by hydraulic nozzles, but at present, rotary atomizers are the most widely used (Bode *et al.,* 1983) The high volume sprayer involves drudgery, high labour requirement, poor coverage, non-uniformity of droplet sizes and run-off which results in reduced effectiveness of pesticides. The very low volume application with a spinning disc c d a sprayer is desirable and practicable (Choudhury, 1984) Hence a battery powered low volume knapsack spinning disc sprayer has been developed, tested in the laboratory and evaluated in the field

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MATERIAL AND METHODS

Description of the newly developed battery powered low volume knapsack spinning disc sprayer and the details of laboratory and field experiments conducted are given below

Description of the low volume knapsack spinning disc sprayer: The sprayer consists of a 10 1 plastic tank and a 6 V rechargeable battery both fixed in a frame which is carried on the back of the operator Spray liquid is taken from the tank to the spinning disc (Heli-Spray make) through a suitable adopter A cut-off valve is provided in the hose line to stop the flow of fluid when desired (Fig 1)

Laboratory Experiments Laboratory test was conducted to determine the average flow rate through the spinning disc by measuring the time

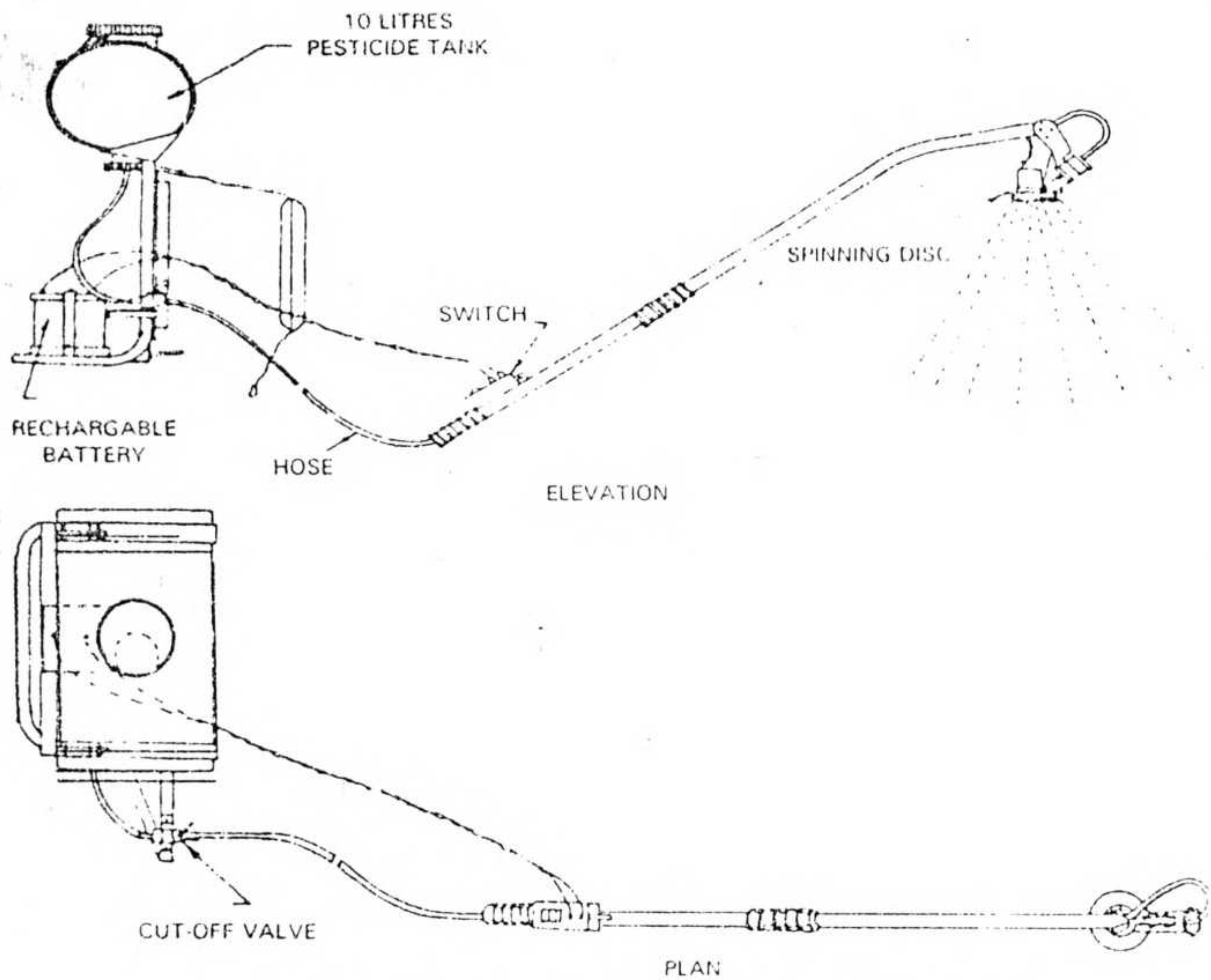

FIG. 1 LOW VOLUME KNAPSACK SPINNING DISC SPRAYER

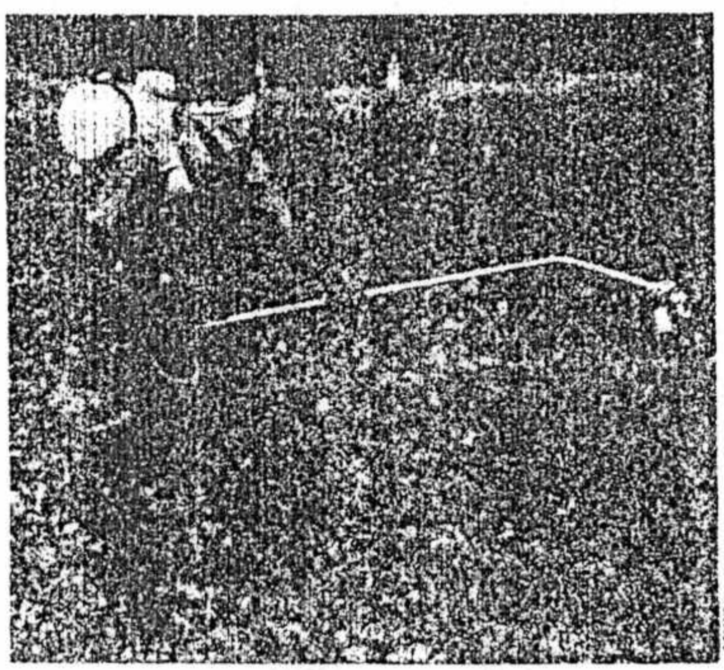

FIG. 2 : LOW VOLUME KNAPSACK SPINNING DISC SPRAYER IN FIELD OPERATION.

taken for the discharge of one litre of water The volume median diameter (v m d) and numerical median diameter (n m d) of the sprayer were determined by the magnesium oxide method (Matthews, 1979; Regupathy and Dhamu, 1990)

Field Experiments The details of treatments were as follows

- T1 - Spraying with low volume knapsack spinning disc sprayer
- T2 - Spraying with Aspee make power knapsack sprayer (mist blower)*
- T3 - Spraying with Hymatic make power knapsack sprayer #
- T4 - Untreated check

Crop	- Cotton, variety MCU 11
Design	- Exploded design
Replications	- Five
Date of sowing	- 16 8 1991
Date of spraying	- 5 12 1991
Insecticide	- Methyl demeton+ 187 5 a i /ha

Pre-count of insect population, cotton leaf hopper *Empoasca devastens* on three leaves viz , top middle and bottom levels in each plant on ten randomly selected plants in each plot was carried out Post-count of leaf hopper population on 1,4,7 and 14 days after spraying was carried out as done for pre-count

RESULTS AND DISCUSSION

The average flow rate through the spinning disc was found to be 9 47 1/ha (Table 1) For an effective field coverage of 0 20 ha/h, the average spray application rate by the sprayer was determined as 47 37 1/ha V m d and n m d of the spray spectrum of the sprayer were determined as 124 30 um and 117 36 um respectively when the battery voltage, amperage and micrometer speed were 5 95 V, 0 57 A and 3423 rev/min respectively

The population of cotton leaf hoppers ranged from 16 4 to 30 6 per 30 leaves before spraying in the field (Table 2) The leaf hopper population came down significantly after spraying with methyl demeton in all the three sprayers evaluated The toxicity persisted upto two weeks after spraying Among the sprayers evaluated, the low volume spinning disc sprayer consistently registered low insect population, ranging from 3 8 to 9 0 per 30 leaves during the period of observation after spraying In the plots sprayed with Aspee power sprayer, the insect population ranged from 3 4 to 9 4 per 30 leaves and in the Hymatic power sprayer plots, the insect population ranged from 5 2 to 12 2 per 30 leaves during the period of observation after spraying

Comparison of treatment revealed the superiority of the low volume spinning disc sprayer (spray application rate-50 1/ha) with the lowest mean leaf hopper population of 7 84 per 30 leaves whereas in the plots sprayed with Aspee and Hymatic power sprayers (spray application rate - 150 1/ha) the mean leaf hopper population were 11 96 and 11 12 per 30 leaves respectively In the untreated check the mean population was 30 00 per 30 leaves

All the three sprayers differed significantly from the untreated check Among the sprayers tested, the low volume spinning disc sprayer differed significantly from the other sprayers tested for comparison

The low volume knapsack spinning disc sprayer costs about Rs 1200/- The operational cost of the sprayer has been calculated to be Rs 25/ha when compared to Rs 35/ha for the power knapsack sprayers, excluding the cost of chemicals

ACKNOWLEDGEMENT

Help rendered by Dr S Pasupathy, Post-Doctoral Fellow and Ms T Gowry, Post-Gradu-

* *Manufactured by M/s American Spring-Pressing Works Limited, Bombay*

\# *Manufactured by M/s Hymatic Agro Equipments Private Ltd , New Delhi, India*

\+ *Metasystox 750 ml of 25 e c*

Table 1

Determination of average spray application rate of the low volume knapsack spinning disc sprayer.

Time taken for discharge of one litre of water, s	Flow rate, 1/h
410	8 78
390	9 23
400	9 00
384	9 38
350	10 29
354	10,17
380	9 47

Average flow rate 9/47 1/h

Average spray application rate for the effective field coverage of 0 20 ha/h

$$= \frac{9\ 45}{0\ 20} = 47\ 37\ \text{1/ha}$$

Table 2

Mean leaf hopper population in cotton (30 leaves)

Period	Treatments				
	T1	T2	T3	T4	Mean
Pre-count	16 4 (3 98^a)	30 2 (5 47^b)	24 2 (4 81^a)	30 6 (5 42^b)	25 35 (4 92)
1 day after treatment	9 0 (2 60^a)	9 1 (2 99^a)	12 2 (3 35^a)	35 6 (5 96^b)	16 55 (3 73)
4 d a t	5 2 (2 10^a)	8 6 (2 86^a)	7 0 (2 59^a)	38 0 (6 10^b)	14 70 (3 41)
7 d a t	3 8 (1 90^a)	3 4 (1 79^a)	5 2 (2 17^a)	25 4 (4 94^b)	9 45 (2 70)
14 d a t	4 8 (2 07^a)	8 2 (2 81^a)	7 2 (2 59^a)	20 8 (4 43^b)	12 50 (2 98)
Mean	7 84 (2 53^a)	11 96 (3 18^b)	11 12 (3 10^a)	30 08 (5 37^c)	15 25 (4 05)

Figures in parenthesis are square root transformed values
In a horizontal column means followed by a common letter are not significantly (statistically) different

ate student, Department of Agricultural Entomology, Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore in taking the insect counts during the course of the study are gratefully acknowledged

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Development and testing of dc motor operated hydraulic sprayer

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Received 27 April 1993

ABSTRACT

A hydraulic sprayer using a gear pump was developed and tested The gear pump was driven by a 12 V, 17W (rated) dc motor Performance of the sprayer was assessed in terms of power consumed, pressure developed, spray pattern, swath width and numerical median diameter (nmd) and volume median diameter (vmd) of the spray spectrum The gear pump developed a maximum pressure of 113 kPa with 310 cc/min discharge at 1390 rev/min of dc motor The peak power consumption of dc motor coupled with gear pump under load was 53 W at 12 V

By 2000 AD, India will need 8 million power sprayers and dusters of 1.5 kW engines (Nagarajan 1990). An average specific fuel consumption of 0 25 litre/kW h and annual use of 300 h for power sprayers (IS . 9164-1979) will result in annual expenditure of Rs 2,700 crores. Gear pump is a positive displacement and self priming used for developing pressure in sprayers in recent years (Smith and Wilkes 1977) Therefore a hydraulic sprayer using a gear pump driven by a 12V, 17W dc motor was developed and tested

MATERIALS AND METHODS

The hydraulic sprayer consists of a gear pump driven by a 12 V, 17 W (rated) dc motor (Fig 1) Inlet of gear pump was connected to a 10 litre capacity liquid container. Outlet was connected to spray lance with triple action hollow cone nozzle through a pressure gauge of 490 kPa (5 kgf/cm^2) capacity. Rated pressure of gear pump is 196 kPa (2 kgf/cm^2) at 1500 rev/min Normally the nozzles of hydraulic sprayers are operated at a pressure of 1 - 3 kgf/cm^2.

The 12V dc motor was operated by 0 - 30 V, 0 - 5 A regulated dc power supply at varying voltages from 6-12 V at 1V intervals Rotational speed of the dc motor was measured by contactless digital tachometer. Ten tachometer readings were taken at each test and were averaged The experiment was repeated after coupling the gear pump with dc motor under no load and at load conditions

Methylene blue powder was added to water at 0.75% on weight basis (Harcharan Singh and Bindra 1975) Discharge through the nozzle was determined. The sprayer was operated for 2 min and water collected in the measuring glass tubes of spray patternator were noted at a nozzle height of 460 mm from the patternator table. Spray distribution patterns were drawn at different volts. Spray width and spray angle were determined from spray pattern curves.

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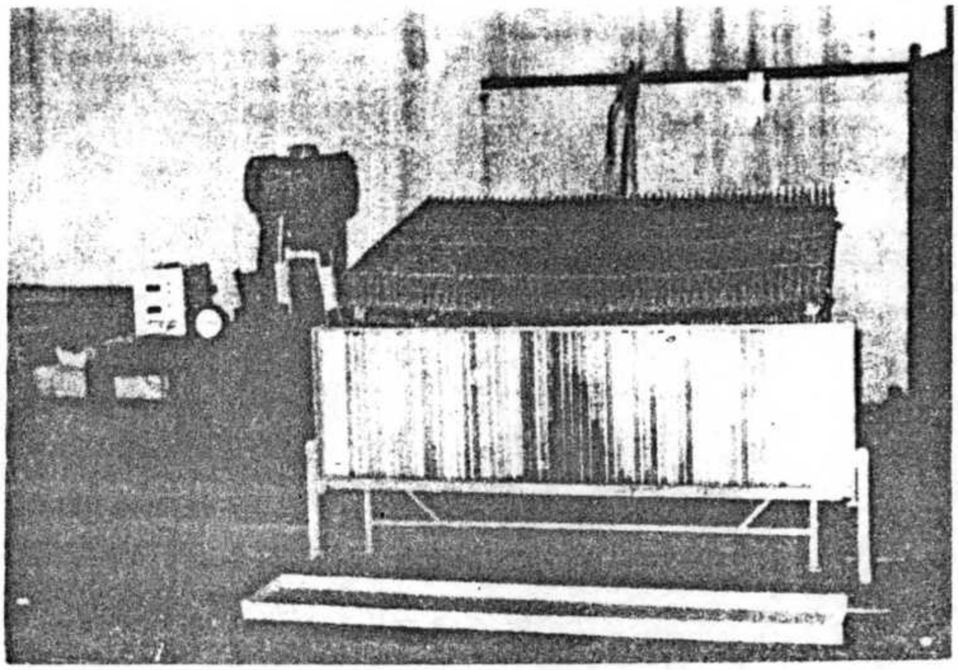

Fig 1 Developed hydraulic sprayer with gear pump driven by 12 V motor

Droplets were collected on glazed photographic bromide paper (Matthews 1979) of 40 mm x 40 mm placed at fixed location, ie 460 mm vertically downwards and 350 mm horizontally sidewards from the nozzle. The droplet diameter on bromide papers were measured after allowing complete spreading of droplets for 24 hours. Spread factor for methylene blue-bromide paper combination was determined by producing uniform size droplets by a low discharge (57cc/min) spinning disc using liquid paraffin and white petroleum jelly (vaseline) mixture in the ratio of 2:1 on weight basis in petridish as standard surface to obtain original sized droplets (Matthews 1975). Numerical median diameter and volume median diameter of the spray spectrum at different voltage were determined (Regupathy and Dhamu 1990).

The experiment was repeated when the dc motor was operated by a fully charged 12 V, 5 A.h lead-acid battery. Battery voltage, motor speed, liquid pressure and discharge were measured at 0,10,20,30 and 40 min of operation. The experiment was replicated twice.

RESULTS AND DISCUSSION

Power consumption of the dc motor coupled with gear pump was 24.48 W at 1818 rev/min under no load at 12V are shown (Table 1).

Table 1 Power and speed of dc motor at varying voltage under different conditions of load

Voltage (V)	Power (W)			Rotational speed of dc motor (rev/min)		
	Motor only	No load	Load	Motor only	No load	Load
8	6.48	15.92	22.00	1323	1125	927
9	7.74	18.00	26.91	1515	12.94	1062
10	9.00	20.00	33.90	1680	1494	1204
11	10.45	22.44	42.35	1830	1669	1272
12	12.00	24.48	53.16	1880	1818	1389

Under load, the peak power consumption of dc motor was 53 16 W at the rated 12 V and resultant speed of pump was reduced to 1389 rev/min The rated rotational speed of 1500 rev/min of gear pump could not be achieved at the rated 12 V under load

Liquid pressure and discharge rate of pump through nozzle increased with increase in motor speed more or less in a linear fashion (Fig 2) The gear pump could develop a maximum pressure of 112 82 kPa at the rated 12V. The corresponding liquid discharge rate was 310 cc/min

The rate of increase in spray width and spray angle increased with increase in motor speed up to 1204 rev/min beyond which the rate of increase in both these parameters decreased (Fig 3) As the motor speed increased the gear pump pumped more liquid through the nozzle increasing the liquid pressure As liquid pressure increased, spray width and spray angle also increased Beyond 1204 rev/min, spray width and spray angle remained more or less the same Therefore the rate of increase in spray width and spray angle decreased beyond the 1204 rev/min of the motor

Both nmd and vmd of spray droplets of the

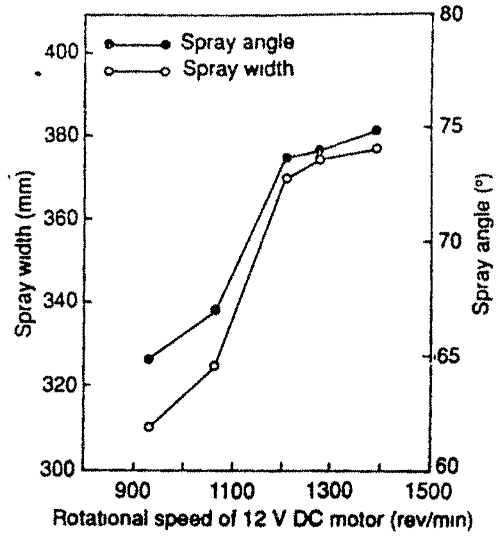

Fig 3 Spray width and spray angle produced by the hydraulic sprayer

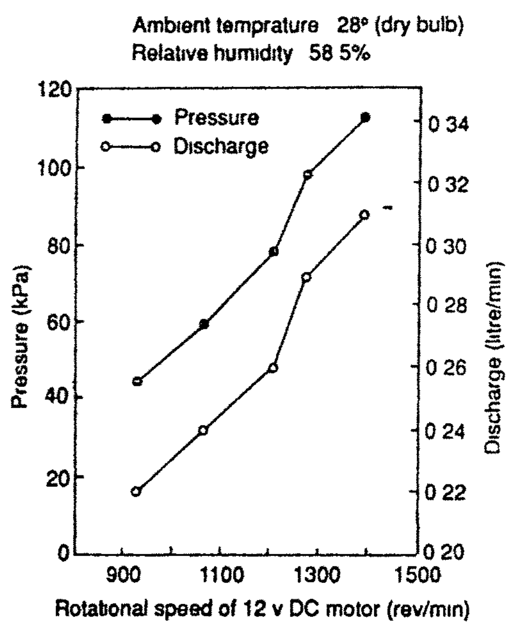

Fig 2 Pressure and discharge developed by gear pump

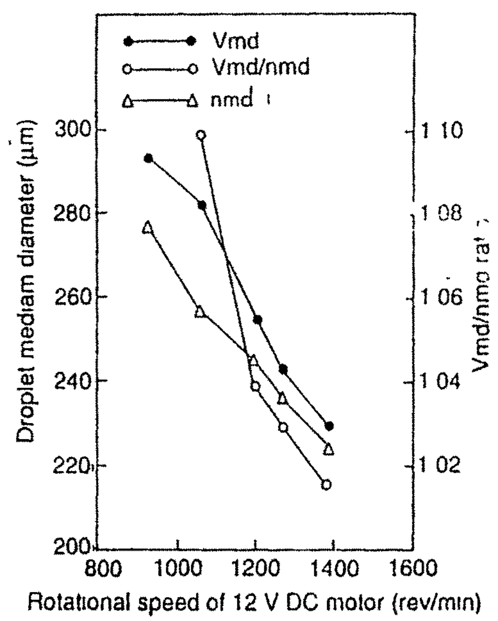

Fig 4 Vmd and nmd of spray produced by the sprayer

Table 2 Battery voltage, motor speed, liquid pressure and discharge during continuous testing of the sprayer with battery

Time (min)	Battery voltage (V)	Rotational speed of dc motor (rev/min)	Liquid pressure (kPa)	Liquid discharge rate (cc/min)
0	12 00	1444	103 0	300
10	11 00	1412	98 1	296
20	10 75	1375	93 2	290
30	10 00	1262	73 6	260
40	6 25	760	14 7	170

sprayer decreased with increase in motor speed (Fig 4) As the motor speed increased by increasing voltage, more liquid pressure was developed The liquid was subjected to more atomisation and nmd and vmd of the spray decreased Vmd nmd ratio decreased from 1 102 to 1 015 when the motor speed was increased from 1062 to 1389 rev/min. More closeness of Vmd · nmd ratio to unity indicates better spray uniformity

Battery voltage, motor speed, liquid pressure and discharge decreased with time when the dc motor-gear pump was driven by a lead acid battery (Table 2) There was sudden decrease in all the above four parameters beyond 30 min operation At 50 min operation the motor ceased to rotate The test revealed that the dc motor could be operated effectively only for 30 min

The gear pump for sprayer should have the capacity to develop 276 kPa and a discharge of 600 cc/min Frictional losses of the gear pump should be reduced so that the pump can be operated by 12 V dc wiper motor at least for 3 – 4 hours with a fully charged battery

ACKNOWLEDGEMENT

The author acknowledges his gratitude to The Pump Engineering Co Ahmedabad for supplying the gear pump for conducting the study.

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ATOMISATION CHARACTERISTICS OF A LOW VOLUME SPINNING DISC SPRAYER

A. Tajuddin[1] and M. Balasubramanian[2]

ABSTRACT

A low volume spinning disc sprayer was developed Tests were conducted to study the effect of varying spinning disc speed on droplet density, numerical median diameter and volume median diameter with different discharge rates at different sampling distances from the spinning disc Nmd and vmd increased as the disc speed decreased, as the sampling distance increased and as the discharge rate increased

I INTRODUCTION

Insecticides applied with hand-carried spinning disc sprayers give similar insect control to that with low volume (lv) sprays applied with knapsack sprayers (Johnstone, et al , 1973) Spinning disc atomisers provide a means of applying crop protection chemicals at volume rates lower than those possible with hydraulic nozzles This advantage coupled with their ability to produce sprays with a narrower size spectrum probably accounts for their increased popularity in recent years (Marchant and Dix, 1986)

Dropsize distribution from a spinning disc atomiser depends on rotational speed or centrifugal force for a given rate of flow At low flow rates and low disc speeds, mass force predominates and the dropsize is primarily an inverse function of centrifugal force, i e the disc speed (Adler and Marshall, 1951)

Frost (1981), in his study to find the effect of disc speed, disc diameter, liquid flow rate, viscosity, density and surface tension on dropsize distribution from rotary atomisers by dimensional analysis, obtained 3 non-dimensional groups, viz $\omega\rho D^2/\mu$, $\sigma D\rho/\mu^2$ and $Q\rho/\mu D$ Subsequently he developed an expression for drop diameter as given below

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$$d = 1.87\ Q^{0.44}\ \sigma^{0.15}\ \mu^{0.017}/D^{0.80}\ \omega^{0.75}\ \rho^{0.16} \quad (1)$$

where d is the drop diameter (m), Q is the liquid flow rate (m^3/s), σ is the surface tension (N/m), μ is the viscosity (Ns/m^2), D is the rotor diameter (m), ω is the rotor speed (rad/s) and ρ is the liquid density (kg/m^3)

Bals (1969) quoted the following equation

$$d = \frac{3.8}{\omega} \cdot \sqrt{\frac{\sigma}{D\rho}} \quad (2)$$

Kamiya and Kayano (1979) produced the following equation for the liquid viscosity not exceeding 20×10^{-3} Ns/m^2

$$d = \frac{2D}{(\sigma/\rho\,\omega^2 D^3)^{0.5}} \quad (3)$$

Ward (1985) evaluated the effects of liquid flow rate, viscosity, surface tension, mass density and disc speed on dropsize distribution through dimensional analysis and derived two dimensionless factors, viz $\sigma^3/\mu^3\omega^2 Q$ and $\rho\sigma^2/\omega\mu^3$, to describe system performance

Bode et al (1983) found that droplet size was inversely proportional to cup speed Droplet size decreased very rapidly for increasing cup speeds up to 2000 rev/min A gradual decrease in droplet size was found for increasing cup speeds above 2000 rev/min

2 EXPERIMENTAL METHOD

2 1 Development of low volume spinning disc sprayer

The commercially available 6 V battery-operated ultra low volume* sprayer (Fig 1) equipped with a 1-litre pesticide can was modified to a lv sprayer for the following reasons (a) The operator has to carry the load of 1 kg spray liquid throughout the field operation, (b) Ulv pesticide formulations are not normally available in

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* ulv - less than 5 l/ha spray application rate and
lv - 10 to 280 l/ha spray application rate for field crops (Varma and Schroeder, 1972, Matthews, 1979, Michael and Ohja, 1981)

Fig 1 6 V battery-operated ULV sprayer

developing countries like India, and (c) The 1-litre pesticide can requires frequent filling which increases the non-operating time The 1-litre pesticide was replaced with a 10-litre tank which is carried on the back of the operator (Fig 2) The 6 V rechargeable lead-acid battery is placed below the tank in the knapsack frame The bore of the dripping nozzle through which the liquid comes out and falls on the spinning disc was increased Spray liquid is taken from the liquid tank to the spinning disc through a plastic hose and a suitable adapter A cut-off valve is provided in the hose line to stop the liquid flow when desired A flow adjustment valve is also provided to vary the discharge rate (Tajuddin, 1991a, Tajuddin, 1991b, Tajuddin et al , 1991c, Tajuddin et al , 1991d, Tajuddin and Subramanian, 1992, Tajuddin et al , 1992)

2 2 Determination of spread factor

Spread factor was determined for glazed bromide paper and methylene blue at 0 75 per cent w/w (Harcharan Singh and Bindra, 1975, Matthews, 1979) Uniformly sized droplets were produced by a spinning disc with low (57 cc/min) discharge (Matthews, 1992) Liquid paraffin and white petroleum jelly were mixed in a 2.1 ratio w/w (Matthews, 1975), and gently heated in a petri-dish until a homogenous mixture was formed The spinning disc was operated at 6, 5 and 4 V Petri-dishes containing the grease matrix and 80 x 80 mm bromide papers were placed side by side Droplets captured in petri-dishes were immediately covered by a thin layer of liquid paraffin and the droplet diameters were measured in a microscope After 24 hours the stain diameters on the bromide papers were measured A spread factor curve was drawn between the average (of 50) stain and spherical droplet diameters

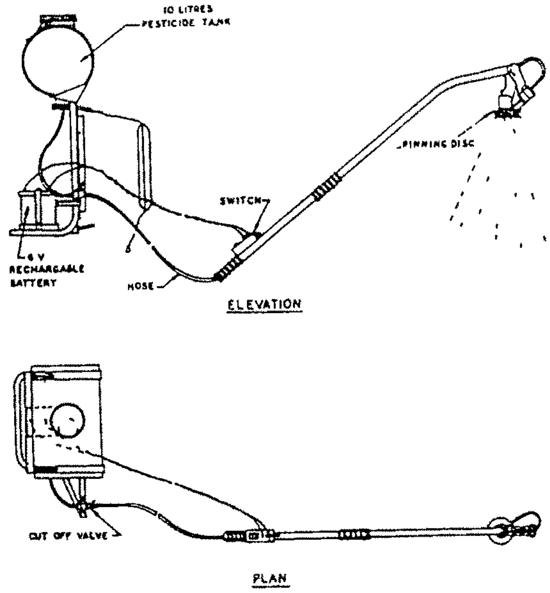

Fig 2 Low volume knapsack spinning disc sprayer

2 3 Testing the low volume spinning disc sprayer

Tests were conducted to determine the flow rate through the spinning disc by measuring the time taken for the discharge of 1 litre of water The spinning disc was operated at 4 to 6 V of the regulated dc power supply provided with digital voltage and amperage displays at 0 5 V intervals with two controlled discharges, viz 57 and 112 cc/min The rotational speed of the spinning disc was measured using a non-contact digital tachometer At each voltage, a minimum of 10 tachometer readings were taken to find the average Bromide papers of 40 x 40 mm were placed 550 mm vertically and at 600, 800, 1000 and 1200 mm horizontally from the spinning disc centre Droplets were captured in the bromide papers for 10s in each test Two replications were made At each voltage, amperage readings were noted to find the power (voltage x amperage) After 24 hours, stain diameters on the bromide were measured and the spherical droplet diameters were found from the spread factor curve Empirical probit values for cumulative percentages of droplet frequency and volume were found from tables and plotted against the log mean diameter of droplets Anti-log of abscissa for the probit value of 5 gives the numerical median diameter (nmd) and volume median diameter (vmd) respectively (Regupathy and Dhamu, 1990) A total of 100 droplet samples were taken to obtain the nmd and vmd data in each test

3 RESULTS AND DISCUSSION

3 1 Spray application rate of the sprayer

The flow rate of the low volume spinning disc sprayer was found to vary from 8 78 to 10 29 l/h For an effective field capacity of 0 20 ha/h, the range of spray application rate by the sprayer was determined as 43 90 to 51 45 l/ha

3 2 Spread factor

There existed a linear relationship between the spherical diameter (y) and stain diameter (x) of droplets following the relationship, y = 0 4x + 104 66 (Fig 3)

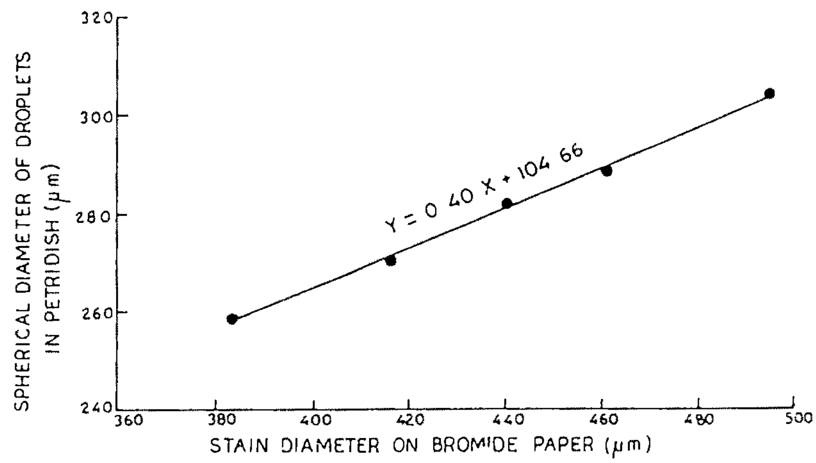

Fig 3 Spread factor curve for methylene blue-bromide paper combination

3 3 Effect of varying voltage on disc speed and power

As the voltage increased, rotational speed of the spinning disc increased under no load and with 57 and 112 cc/min discharge rates (Fig 4) The rate of increase of disc speed decreased with increase in voltage in all the above three cases Maximum no load disc speed was 3927 rev/min with 5 72 W power consumption at the rated 6 V With 57 cc/min discharge rate, the maximum disc speed was 3578 rev/min with 5 7 W power With 112 cc/min discharge rate, the power was 5 82 W at 3515 rev/min disc speed Power increased when the disc speed increased The rate of increase of power increased with the increasing voltage or disc speed (Fig 5) There was no appreciable difference in power consumption between 57, and 112 cc/min discharge rates

3 4 Drop size distribution

Both nmd and vmd of spray decreased as the spinning disc speed increased Nmd and vmd were close to each other at both 57 and 112 cc/min discharge rates Both nmd and vmd increased as the sampling distance from the spinning disc increased and also as the discharge rate increased (Fig 6 and Fig 7)

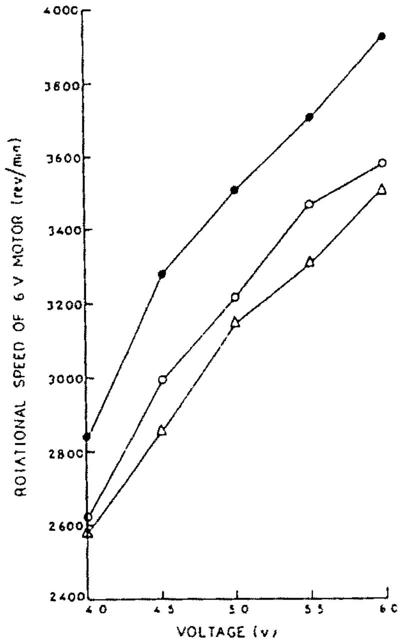

Fig 4 Rotational speed of 6 V motor at varying voltage, -•- no load, -o- 57 cc/min discharge, -△- 112 cc/min discharge

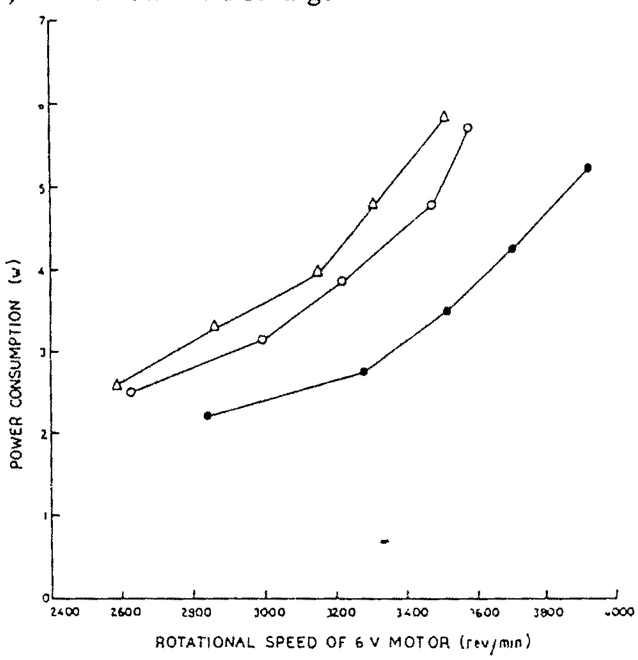

Fig 5 Power consumption of 6 V motor at different discharges through spinning disc, -•- no load, -o- 57 cc/min discharge, -△- 112 cc/min discharge

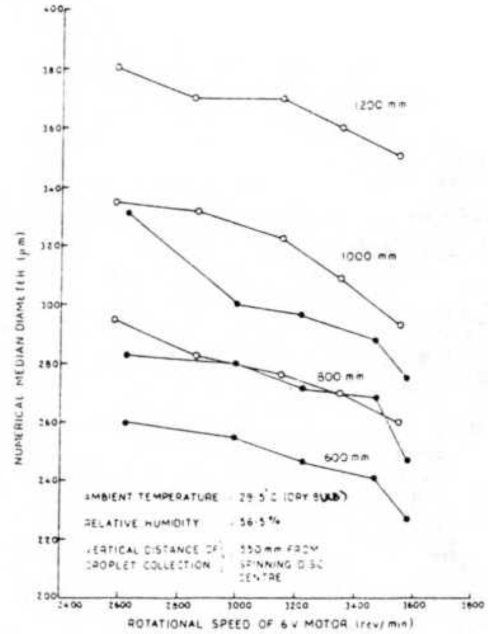

Fig. 6: Nmd of spray from 6 V motor operated spinning disc, -•- 57 cc/min discharge, -o- 112 cc/min discharge

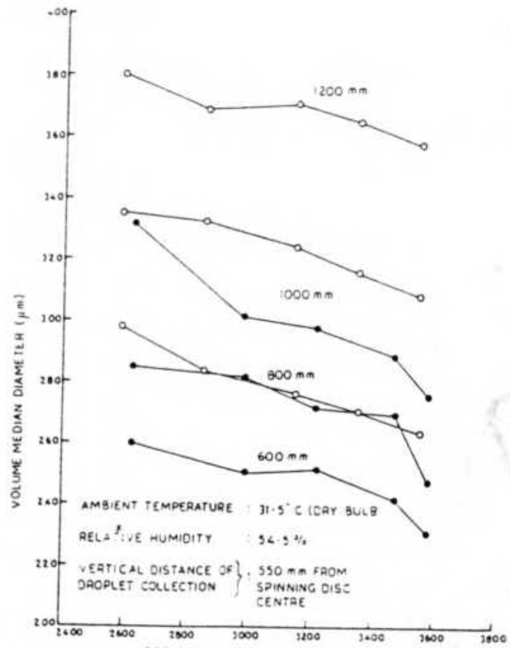

Fig. 7: Vmd of spray from 6 V motor operated spinning disc, -•- 57 cc/min discharge, -o- 112 cc/min discharge

The nmd and vmd of the main satellite spray cloud were 247 and 248 μm respectively at 800 mm distance from disc centre at the rated 6 V with 57 cc/min discharge rate With 112 cc/min discharge rate both the nmd and vmd of the main satellite cloud were 276 μm at 1000 mm from the disc centre This might be due to the increase in drop size at higher discharge rate, the heavy droplets travelled more distance from the disc centre overcoming the aerodynamic drag

Increase in disc speed resulted in increase in the number of droplets captured per cm^2 area at 600 and 800 mm distances from the disc centre At 1000 and 1200 mm distances from the disc centre, increase in disc speed resulted in a decrease in the number of droplets/cm^2 (Fig 8) The above phenomenon was observed for both 57 and 112 cc/min discharge rates As the disc speed increased, drop size decreased and as a result more droplets were captured per cm^2 area at lower sampling distances But dropsize increased as the sampling distance increased Due to this, the number of droplets/cm^2 decreased with increasing disc speed at higher sampling distances

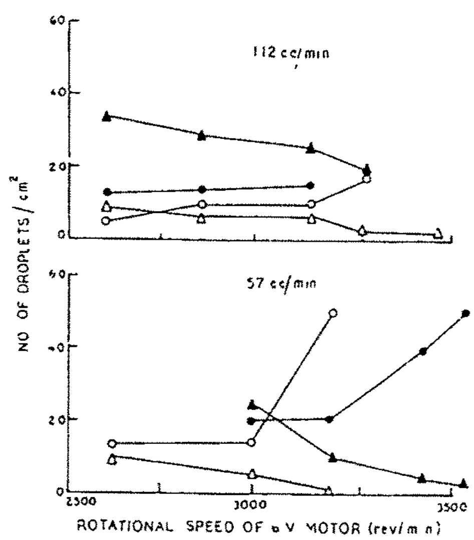

Fig 8 Number of droplets captured at different distances from the disc centre, --•- 600 mm, -o- 800 mm, -▲- 1000 mm, -△- 1200 mm

3 5 Countinuous testing of the sprayer with battery

As the operating time elapsed, both the battery voltage and amperage decreased (Fig 9) However, the rate of decrease in voltage and amperage decreased with the operating time By relating the results plotted in Fig 10 to those in Fig 6 and Fig 7 it could be inferred that both nmd and vmd increased with the elapse of the operating time The disc speed decreased with operating time more or less at a constant rate Power consumption of the 6V motor decreased with the operating time But the rate of decrease of power decreased with the operating time (Fig 10)

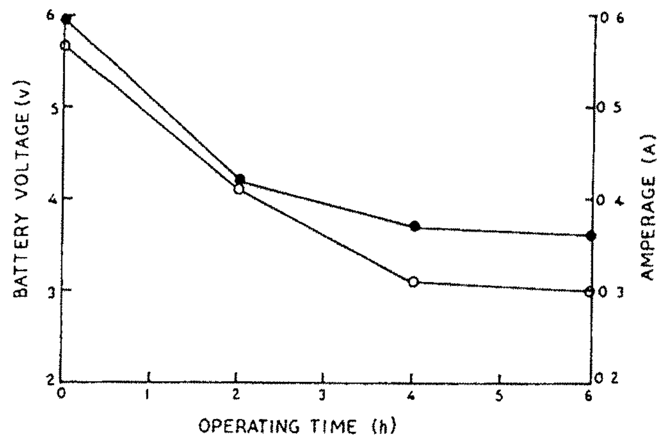

Fig 9 Battery voltage and amperage during continuous operation, -•- voltage, -o- amperage

4 CONCLUSIONS

Spray application rate of the sprayer was found to vary from 43 90 to 51 45 l/ha There was not an appreciable difference in power consumption of the motor when the discharge rate was increased from 57 to 112 cc/min The main satellite spray cloud was observed to shift from 800 to 1000 mm from the spinning disc centre when the discharge rate increased from 57 to 112 cc/min

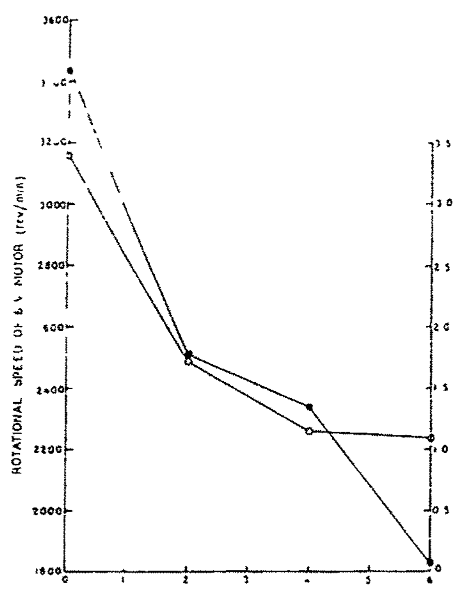

Fig 10 Motor speed and power during continuous operation, -•- speed, -o- power

Both nmd and vmd decreased as the disc speed increased which is in conformity with the studies conducted by Bals (1969), Kamiya and Kayano (1979) and Bode et al (1983). As the sampling distance from the spinning disc increased, both nmd and vmd increased The droplet size increased as the discharge rate through the spinning disc increased which was in accordance with the results obtained by Frost (1981)

At 800 mm deposition distance of the main satellite spray cloud from the spinning disc centre and at the rated 6 V, nmd and vmd obtained were 247 and 248 μm respectively with 57 cc/min discharge rate At 1000 mm deposition distance of the main spray cloud from the disc centre, both nmd and vmd obtained were 276 μm with 112 cc/min discharge rate As the operating time increased, nmd and vmd increased, and battery voltage, amperage, power and disc speed decreased

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