Technology reports

A slotted rotary drum atomizer

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Summary

A slotted rotary drum atomizer was designed, consisting of an open-ended, thick walled, rotating plastic cylinder with a series of longitudinal slots. The liquid distribution system consisted of a bronze metal liquid feed channel with holes leading to a series of grooves on the insides of the vanes between the slots. The open ended design allowed the drum to act as a small centrifugal fan. The design is simpler and cheaper than metal cage and rotary drum atomizers.

Preliminary experiments suggested that droplet spectra produced are similar to those produced by rotary cage atomizers. Visual observations under high frequency strobe lighting showed that liquid distribution along and around the drum with the liquid distribution system developed, was more uniform than that produced by simple jetting onto the inner surface of the drum and also suggested that liquid feed uniformity has a significant effect on droplet size and uniformity. However, resources to measure and quantify this effect, the effect of air movement through the slots and the effect of liquid flow rate on droplet spectra were not available.

With a 50 mm diameter drum rotating at 7000 rev min^{-1}, the maximum air velocity produced was 14 m s^{-1} at approximately two thirds of the drum length from the open end. This self generated air-blast means that the unit could be used in air assisted spraying systems without the need for a separate fan or blower.

To eliminate the need for high speed gearing, high speed piston style hydraulic and high frequency, a.c. electric motors have been developed as suitable drive systems that are cost effective, energy efficient, robust and reliable. Fitted with windmill blades, the atomizer should also be suitable for use on agricultural aircraft.

Introduction

Aims

The aim was to develop an atomizer for use in combination with efficient air assisted spraying systems.

The use of airstreams of large cross sectional area at lower velocities are most efficient in energy use and in spray coverage of the target (Randall 1971). Turbulent air also improves the uniformity of spray coverage and improves spray penetration into dense plant canopies (Furness and Pinczewski 1985).

Some chemicals require high volumes and full wetness for good efficacy. On the other hand, low volume spraying reduces the cost of spray application. Hence it is desirable for nozzles to have flexibility for high or low flow rate.

Fine droplets give better spray coverage with lower spray volumes, provided impaction efficiency is not too low (Matthews 1979). Air assistance increases impaction efficiency, enabling finer droplets to be used. However, most nozzles producing fine droplets have low maximum flow rates.

The following nozzle parameters are considered as desirable for efficient air assisted spraying:-

a) High as well as low flow rate capability (250 mL min^{-1} to 30 L min^{-1}),
b) Capable of producing fine droplets (vmd near 100 microns),
c) Delivery of droplets into large volumes of air,
d) Good control of droplet size, approaching CDA (CDA: nmd/vmd ratio < 2),
e) Robust and reliable.

Rotary atomizers

Radial droplet emission means that rotary atomizers can distribute droplets in large volumes of air, whereas nozzles, such as hydraulic cones, fan jets and air shear nozzles, emit droplets from a point source. Hence rotary atomizers may be more suitable for air assisted spraying.

Controlled droplet atomizers

Controlled droplet application (CDA) atomizers have been promoted for improving the efficiency of agricultural spraying by producing a relatively narrow droplet size spectrum that can be varied to suit the target or operating conditions (Bals and Agr 1978, Matthews 1979, Banks *et al.* 1983 and Spillman 1983). Most atomizers that have been developed for CDA or for producing fine droplets (including air shear nozzles, spinning discs, and the disc-windmill atomizer (Spillman and Sanderson)) are not capable of giving high flow rates, making them unsuitable for high volume spraying. Many rotary disc atomizers also suffer from the disadvantage of not being robust.

However, many authors have claimed that variation in droplet size can be desirable and the advantages of CDA for improving spraying efficiency have not been well established.

Rotary cage and rotary drum atomizers

These atomizers can produce fine droplets combined with high flow rate capability and with droplet size range that can approach CDA (Parkin 1983). They can also be robust, but capital cost is high relative to most other atomizers.

With rotary cage atomizers the wider droplet size range is partly caused by some of the liquid not reaching the peripheral speed of the cage before emission, and by impaction and uneven liquid distribution on the periphery of the cage (Parkin 1983, Pettenkoffer 1983 and Rokicki and Wills 1987). A thin walled slotted metal drum is used on the Span Sprayer (Ring Around Products, Inc., Montgomery, Alabama, USA). Droplet size range is similar to the rotary cage atomizers. Thin walled slotted rotating metal drums have also been developed in Hungary for use in aerial application which give less variation in droplet size (Pettenkoffer 1983). The Beecomist metal foam rotating sleeve also gives less variation in droplet size (Howitt *et al.* 1980), but this atomizer is readily blocked by agricultural chemicals. Thick walled rotating metal foam atomizers with lower density foam also produce less variation in droplet size (Parkin 1983), but they have not been commercially developed.

A separate liquid distribution system is used in all of these rotary cage and drum atomizers.

Drive systems for rotary drum and cage atomizers

Fan assisted rotary cage or drum atomizers on multi-head, air assisted ground sprayers (Furness and Pinczewski 1985) are normally driven by gear type hydraulic motors. These motors are restricted to a maximum of about 3000 rev min^{-1}, giving a minimum mean droplet size of about 200 µm (Walton and Prewett 1949). To produce droplet sizes of around 100 µm volume median diameter (vmd), gearing up to 6000–10 000 rev min^{-1} is required. Gear or belt drives are expensive, mechanically complex, suffer reliability problems, and add weight.

Spinning disc atomizers on hand held or boom sprayers are normally driven by small low voltage d.c. electric motors. However, low voltage d.c. electric drive is unsuitable for the higher power required for spinning cage or drum atomizers, especially where the motor also drives an axial fan, which normally requires a power input of 1 kW or more. These larger d.c. motors require air cooling through open ducts which permit the entry of dust and spray into the motor.

Axial fans are commonly used to spin rotary atomizers on aircraft and in the airstreams of some air-carrier orchard sprayers. They are a cheap and mechanically simple way of driving these atomizers, especially on aircraft, but not suited to all types of air assisted sprayer. Maintaining precise rotational speed is also difficult.

Rotary drum atomizers were considered to be the only type currently available that could incorporate all the desired parameters for efficient air assisted spraying. However, high capital cost relative to other atomizers was seen as a major disadvantage. The development of a cheaper rotary drum atomizer with a liquid distribution system incorporated into the drum itself is reported. Preliminary droplet spectra analysis studies were carried out and airflows associated with the drum were measured. Alternative high speed drive systems were also investigated.

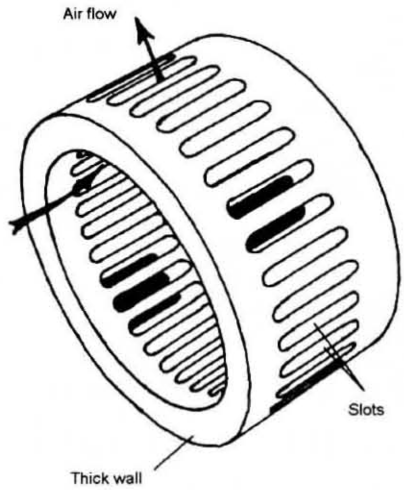
Atomizer design

The design tested consists of an acetyl plastic cylinder, open at one end, with a series of longitudinal slots milled through the thick cylinder wall leaving a series of vanes between the slots (Figure 1.).

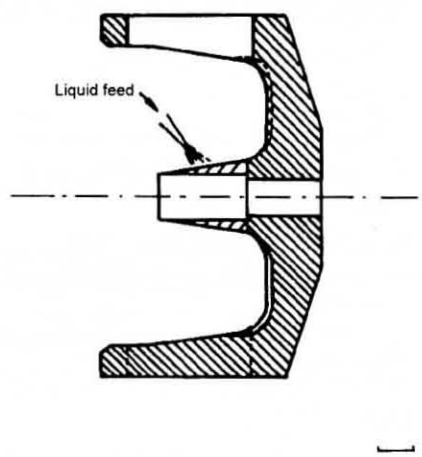
Initially, liquid was simply jetted onto the inner surface of the drum from holes drilled into a hollow shaft collar which extended inside the drum (Rokicki and Wills 1987). Observations under strobe lighting showed that liquid distribution was uneven both radially and axially over the drum surface and the departure path of liquid through the slots was via the leading face of the vanes (Figure 2.). The use of more jets or their replacement with small plastic microjets normally used in irrigation systems improved the liquid distribution, but it was still uneven.

Two liquid distribution systems, moulded into the cylinder, were examined. In one design (Figure 1b), the liquid was fed onto the central spinning shaft, and directed to the insides of the vanes by a series of grooves around the end of the drum. The inside of the cylinder was ta-

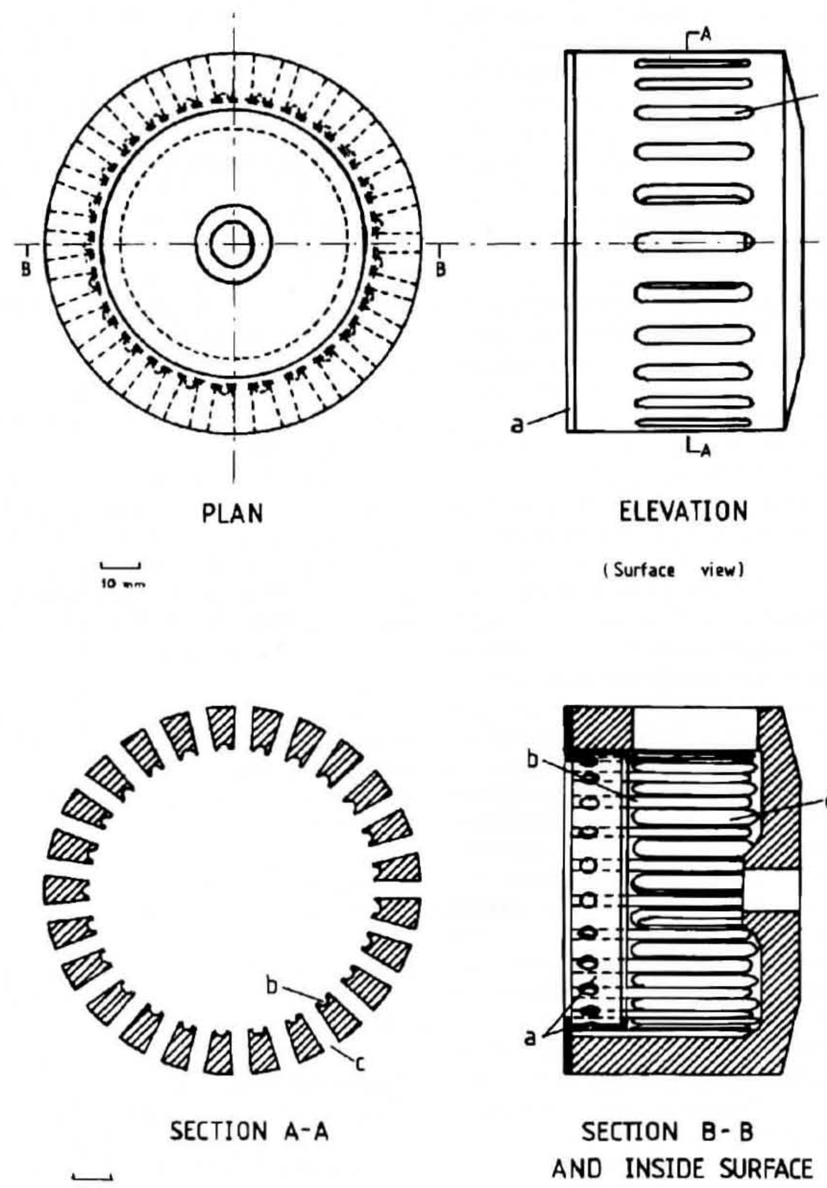
Figure 1. Designs of 100 mm diameter plastic slotted rotary drum atomizers.



(a) General diagram

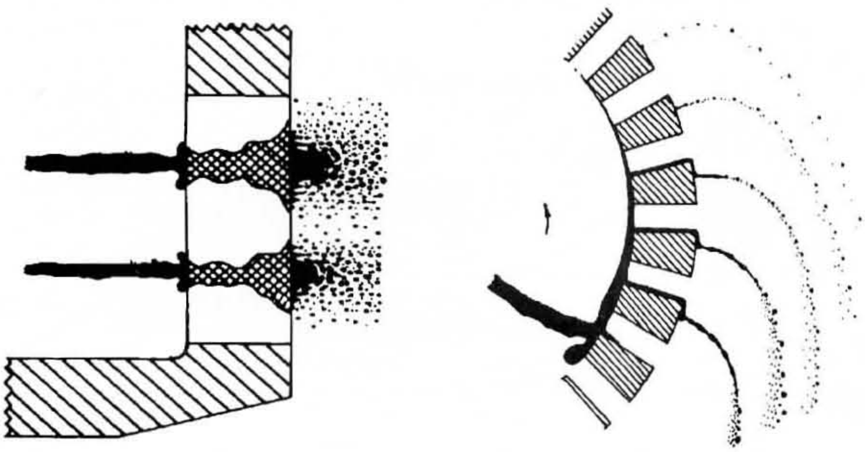


(b) Prototype 100 mm diameter drum with liquid feed via central spinning shaft to grooves



(c) Prototype 100 mm diameter drum with liquid feed via metal annulus with channel and holes to grooves. a) bronze annulus, b) liquid feed groove, c) slots

Figure 2. Visual observations of liquid flow path through an ungrooved slotted rotary drum atomizer when liquid is jetted directly onto the inside of the drum.



(a) longitudinal section through slot (b) cross section across the slots
Solid black areas represent liquid flow, ↑ direction of rotation.

Figure 3. Commercial Auspray (Vogt Engineers Pty Ltd, Tarlee, SA) 150 mm diameter drum with annular liquid feed collar and axial fan.

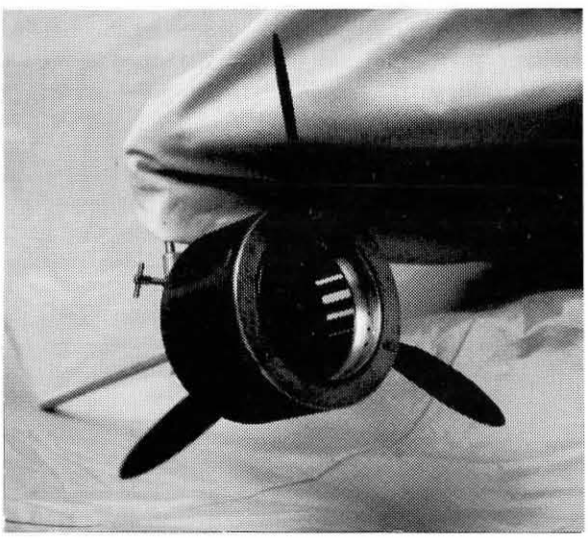
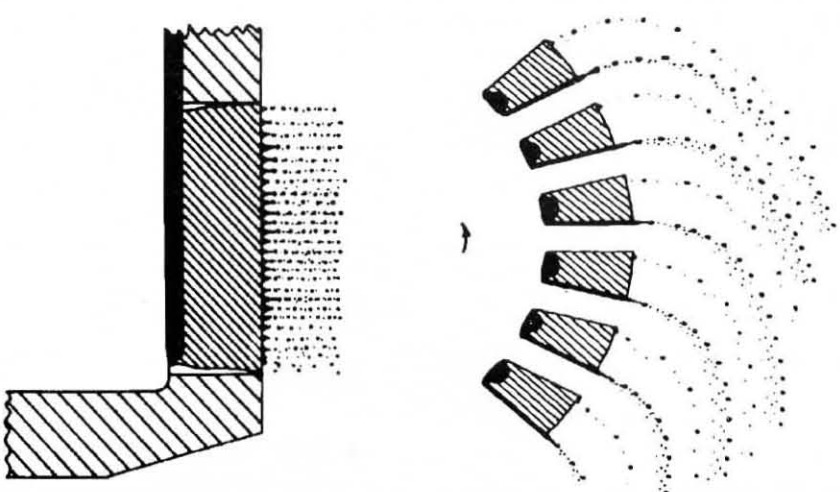


Figure 4. Visual observations of liquid flow path through a grooved slotted rotary drum atomizer.



(a) longitudinal section through slot (b) cross section across the slots
Solid black areas represent liquid flow, ↑ direction of rotation.

pered slightly to help spread the liquid more uniformly. In the second design (Figure 1c), the liquid was fed into an annular metal channel at the open end of the drum which led into a series of grooves on the inside of each vane via holes in the channel. The second design was adopted because it is simpler to manufacture and gives more even liquid feed. Observations with strobe lighting showed that the liquid distribution was relatively even both radially and axially over the drum surface. The liquid path was mainly via the trailing face of the vanes (Figure 4), which indicated that the liquid had reached the speed of the drum before entering the slots. Improved liquid distribution permits the use of higher flow rates before flooding begins to occur.

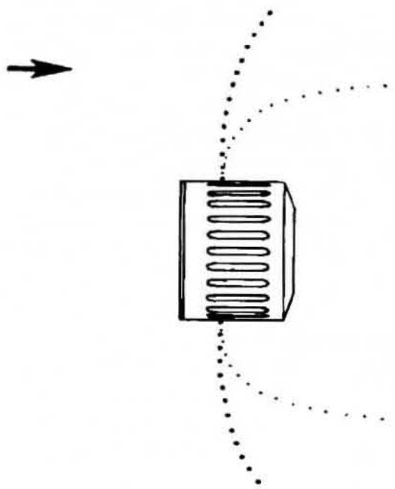
Figure 3 is a photograph of a 150 mm diameter drum in commercial use in an Auspray (Auspray Pty Ltd, Waikerie, South Australia) fan assisted, multi-head, orchard sprayer (Furness and Pinczewski 1985), showing the drum and axial fan.

Atomization process

Droplets are formed by a combination of centrifugal force (the major mechanism in conventional rotary atomization) and air forces. The rotation of the drum causes it to become a centrifugal fan in which air is blown through the slots located around its circumference. We suggest that the friction of this air flow causes the liquid to be drawn off more quickly and with possible effects on ligament and droplet formation. This effect should increase the maximum output from the atomizer before flooding occurs. Such effects are reported for the disc-windmill atomizer (Spillman and Sanderson 1983).

However, droplet sizes produced by a prototype atomizer were similar to those from other rotary drum or cage atomizers and the airflow produced only a relatively minor, but significant effect (Rokicki and Wills 1987). The liquid feed system for this atomizer consisted simply of jets of liquid directed onto the inside surface of the drum, which probably produced localized surface flooding which could have reduced the airflow effect. Later experiments (unpublished), using low flow rates showed that the airflow does in fact exert a strong influence on droplet formation. At high flow rates (about 5 L min^{-1}) this appears to be confirmed by our visual observations of droplet trajectories in the open in wind conditions of 10–15 km h^{-1} (Figure 5), which showed that the larger droplets produced by simple liquid jetting onto the inner surface of the drum disappeared when the improved liquid feed system was used. More detailed studies are needed, but to date, resources have not been available.

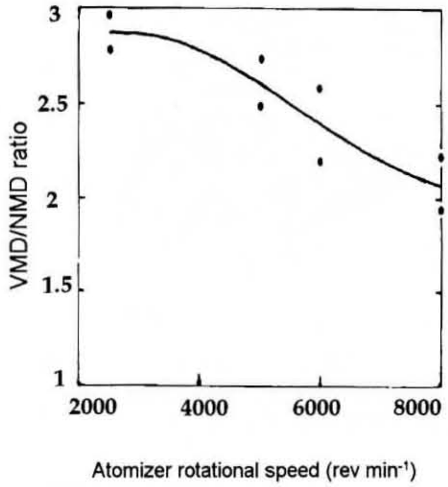
Figure 5. Effect of droplet size on trajectories of larger and smaller drops from a slotted rotary drum atomizer outdoors in a 10–15 km h^{-1} wind.
→ wind direction, (•) large droplets, (•) small droplets



Droplet size

Preliminary droplet size studies, using water plus 0.1% v/v Agral as a surfactant, were carried out using a 100 mm slotted drum with liquid feed ring. A Malvern ST 1800 droplet size analyser was used to measure vmd and nmd at rotational speeds from 2000 to 8000 rev min^{-1} using a flow rate of 150 mL min^{-1}. The results of two replicates at each speed are given in Figures 6 and 7. The vmd/nmd ratio is similar to that produced by Micronair rotary cage atomizers and higher than that for spinning discs (unpublished data). It would be interesting to determine how the airflow influences vmd and vmd/nmd ratios at higher flow rates when compared to a rotary cage atomizer. The results with solvents other than water would also be worth investigating.

Figure 6. Effect of atomizer rotational speed on VMD/NMD ratio with water + Agral wetter at 150 mL min^{-1} flow rate with a 100 mm diameter slotted rotary drum atomizer.

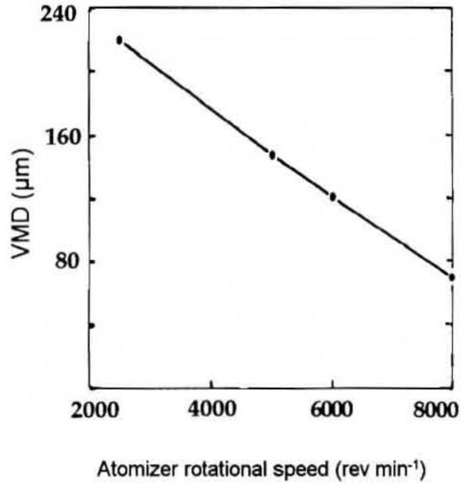


Airflow characteristics

The open ended slotted drum acts as a centrifugal fan. Air velocities for a 50 mm diameter, 50 mm long drum, in both open and closed configurations, were measured in earlier work (Rokicki and Wills 1987).

Complete air velocity distributions, about 5 mm from the drum surface, were measured with a hot wire anemometer along the surfaces of a 50 mm slotted drum, a Micronair AU5000 in standard 102 mm diameter wire cage form and a 102 mm diameter slotted drum fitted to the Micronair in place of the wire cage. Due to difficulties in adapting the design, the slotted drum fitted to the Micronair had no open end and hence did not function as an air blower.

Figure 7. Effect of atomizer rotational speed on VMD with water + Agral wetter at 150 mL min^{-1} flow rate with a 100 mm diameter slotted rotary drum atomizer. (Replicates were within 1–3% of the mean).



Both the Micronair and the modified Micronair showed that similar air speeds existed near their surfaces (Figure 8). These air velocities, of 1–4 m s^{-1} in the direction of rotation, were probably attributable to frictional forces between the air and the rotating drum. It is unlikely that this air movement would produce any worthwhile air/liquid interaction.

When free air intake was allowed using the 50 mm slotted drum at 7000 rev min^{-1}, air discharge velocity increased greatly over much of its surface when compared to the same drum at the same rev min^{-1} fitted with a flange that blocked the air intake and hence discharge (Figure 9). The amount of airflow varied axially along the drum and reached a maximum of 14 m s^{-1} at about two-thirds of the drum length from the open end. The air discharge had

Figure 8. Air velocity near the surface of a Micronair AU5000 fitted with the standard wire mesh cage and a closed plastic slotted drum, at 3000 rev min^{-1}.
o--o Standard wire cage. •—• Slotted drum (closed).

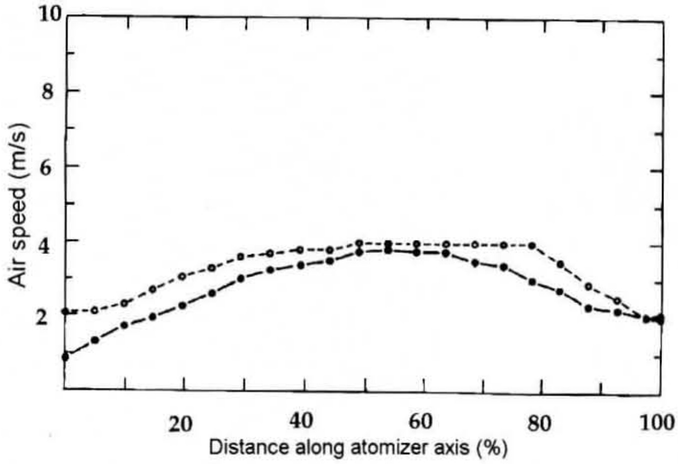


Figure 9. Air velocity near the surface of a 50 mm diameter slotted drum atomizer with blocked and open air inlet, at 7000 rev min^{-1}.
o--o Open air inlet. •—• Closed air inlet

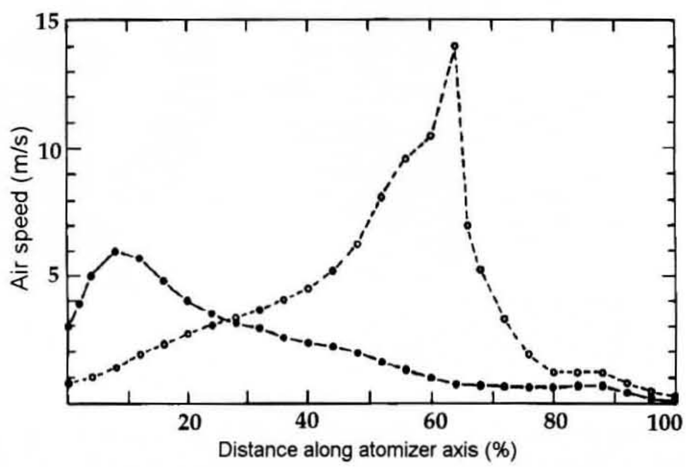
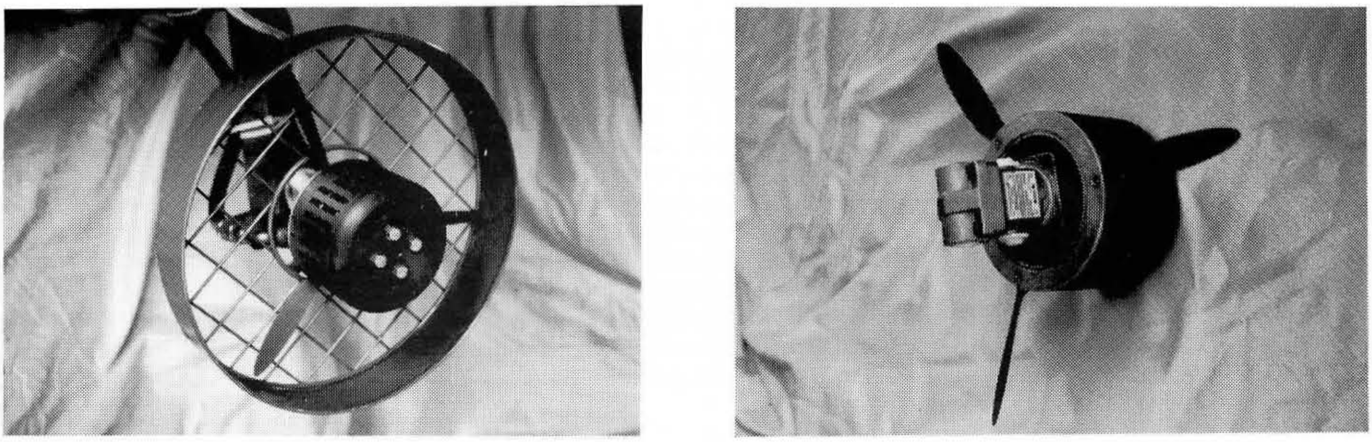


Figure 10. Commercial Auspray spray head showing the location and mounting of the high speed, piston style, hydraulic drive motor.



a strong radial component, reaching a radial distance of at least 0.5 m from the drum. It is likely that this air movement would produce a significant air liquid interaction as suggested by observations on droplet size at high flow rates.

To date the drums have been used only in combination with axial fans in multi-head, air-carrier orchard sprayers (Furness and Pinczewski 1985). These spray heads are considerably cheaper than similar high speed spray heads. Possibilities exist (without the extra fans) for utilizing the self generated air output to carry droplets onto plants where the atomizer is close to the target, for example, in row crops.

Drive systems

Hydraulic drive

High speed, piston type, fixed displacement hydraulic motors (Mannesmann Rexroth GmbH, No A2F, Series 6.0) have been used to spin an assembly consisting of a slotted rotary drum atomizer and an axial fan (Figure 10) at 6000–7000 rev min^{-1}.

The power requirement (including the fan and drum) measured on the drum drive shaft was 1 kW (± 50 W) and measured by power input to the hydraulic pump was 3–4 kW per head. Shaft and bearing loadings were 20 Newtons which is within the specifications of the motor. This style of motor, although more expensive than conventional gear motors, eliminates the need for high speed gearing, which is required with gear motors to obtain rotational speeds above 3000–4000 rev min^{-1}. The energy efficiency of piston motors and pumps is better than with gear types. A drum size of 150 mm diameter has been used so that the drive motor fits inside the drum with adequate room for air intake, eliminating the need for extended shafts. Observations suggest that the large diameter compared to other drums also increases the maximum flow rate before surface flooding occurs. All these features reduce complexity, weight and overall cost and improve the reliability (experience) of this type of spray head. Total weight is approximately 4 kg compared to weights of up to 20 kg for other spray heads with gear motors and gearing. The simple design enables considerable labour savings in construction.

Figure 11. Prototype, high frequency (variable), 240–300 V a.c., three phase, induction drive motor with 100 mm diameter slotted rotary drum atomizer and liquid feed collar attached.

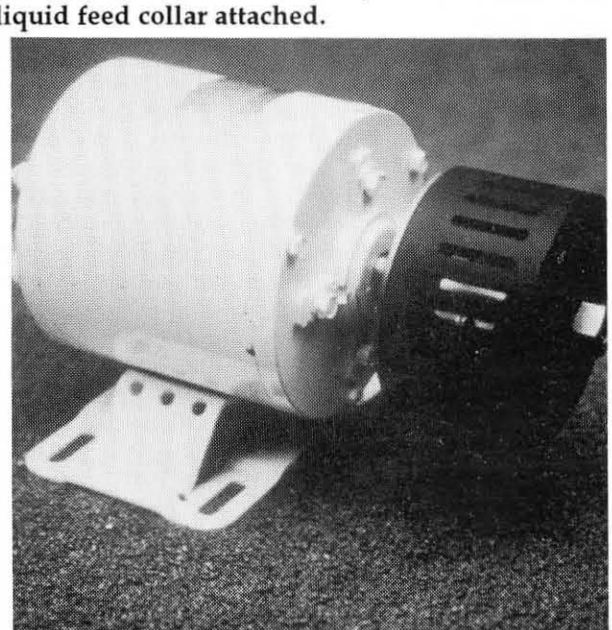
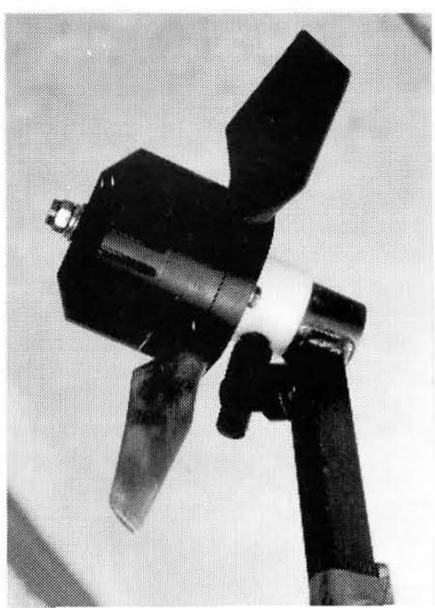


Figure 12. Prototype slotted rotary drum atomizer fitted with variable pitch windmill blades for use on agricultural aircraft.



High frequency a.c. electric drive

Alternating current electric drive (208 V, 3 phase, 400 Hz, 900 W at 11 600 rev min^{-1}, IP-55 standard) has been used to drive the Unirot-4 rotary drum atomizer in Hungary (Pettenkoffer 1983). This drive gives reliability, energy efficiency and gives precise control over rotational speed.

We have developed a similar motor (Figure 11) to drive a 100 mm slotted drum for use on a bluff plate sprayer (Furness 1991) based on readily available, standard 415 V, three phase, two pole, 50 Hz motor components. These have been modified to permit variable range high-speed operation and to provide sealing and protection against corrosion under the harsh environment. At the nominal output rating of 100 W, at 240 V, 120 Hz and 7000 rev min^{-1}, the actual input, depending on liquid flow rate, is about 120–180 W. The cost of the motor was similar to a conventional 50 Hz, three phase motor of similar size and type.

The power supply was initially obtained from a static, variable frequency inverter which was energized from a standard 50 Hz alternator. This was replaced after the development and manufacture of a special four pole, three phase alternator that used a rotating permanent magnet system incorporating rare earth neodymium material. The resulting totally enclosed alternator was compact, and being matched to the motor requirements, needed no electrical controls. Motor speed was directly proportional (about twice) to the speed of the alternator. The nominal output was 1000 W at 120 Hz and 3600 rev min^{-1}. The alternator was powered by a stationary petrol motor and speed could be adjusted by adjusting the speed or the motor. The system is not in commercial production.

Windmill drive

With the help of Crowthair Pty Ltd, Adelaide, an experimental prototype atomizer was manufactured and fitted with variable pitch windmill blades for use on agricultural aircraft (Figure 12). With the inbuilt liquid feed system, a separate liquid feed system was not required. A single atomizer was fitted to an agricultural aircraft by Crowthair. A windmill driven version of the atomizer has not been commercially produced.

Conclusions

The new plastic rotary drum atomizer offers a low cost alternative to other rotary drum/cage atomizers. Visual observations suggest that the uniformity of liquid distribution to the atomizing surfaces was a major factor in improving the uniformity of droplet sizes produced, but further quantitative studies would be required to quantify this. The new liquid feed system gave a major improvement in the uniformity of liquid distribution along and around the drum, with the added advantages of simplicity and lower cost.

Both the high speed hydraulic drive and the high frequency a.c. electric drive have advantages over other rotary atomizer motors currently in commercial use and have proven reliable in the field. Either drive can be easily fitted to the atomizer, depending on circumstances. Windmill blades could be fitted to the atomizer for use on agricultural aircraft.

The effects of air flow, liquid flow and atomizer geometry on droplet size spectrum warrant further study. A more fundamental knowledge of the influence of these variables could lead to design refinement. One example where this might prove fruitful is in aerial application, where droplet size control is of critical importance to preventing off-target spray drift.

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