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Rotary atomiser design requirements for optimum pesticide application efficiency

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ABSTRACT

Pesticide application efficiency from aircraft could be increased substantially, and required downwind buffer distances to avoid drift damage reduced significantly, if sharp issuing points or pins were added to existing rotary cage atomizer designs. This would enable existing rotary cage units, already successfully deployed for Ultra Low Volume (ULV) applications of insecticides, to be also used for Large Droplet Placement (LDP) application of herbicides. Studies at Cranfield University using high speed photography and laser droplet sizing instrumentation demonstrated that the addition of fine pins to the final atomizing surface of the rotating cage would increase uniformity of droplet production, by promoting fluid atomization in the ligament mode. This would lead to a substantially increased percentage of droplets in the spray falling between 100 μm and 300 μm in size, suggested here as a biological/environmental droplet size optimum. Development of a 'spinning pins' rotary atomizer for aircraft would therefore be highly desirable for agricultural and other purposes. Investment in this technology has the potential to significantly reduce pollution of atmosphere, soil, fresh water and oceans with pesticides.

1. Introduction and background

During the twentieth century, pesticides enabled food producers to intensify agricultural production, which was necessary to feed a growing world population which grew in that time from 1.6 billion to over 6 billion. In 1962, Carson with her work with predatory birds was probably the first to recognize damage that pesticides could cause to the environment. It was not until the 1980s that any specific actions were taken by governments, this mainly in reaction to specific human health issues eg. organochlorines in milk and beef.

The waters that surround Australia comprise the only remaining fishing ground globally, that has not been severely depleted through overfishing and pollution. But serious impacts upon the Great Barrier Reef (GBR), specifically from herbicide and nutrient contamination (actually a greater impact than sea surface temperature) are now starting to be quantified. It is predicted by many scientists that if intensification along Australia's NE coastal fringe continues at its present pace, the GBR will disappear by the middle of this century. Pesticide environmental management strategies include i) spraying only in cool neutral conditions with a breeze blowing spray away from any sensitive areas, ii) use of buffer zones – either leaving a portion of the crop unsprayed, or using tree buffers, and iii) use optimum nozzle configuration and settings for reduced drift. The latter usually involves coarsening droplet size to the maximum possible with a conventional hydraulic nozzle. But this has the problem that it reduces application efficiency, and therefore more pesticide has to be applied to obtain the same biological result.

The efficiency of pesticide application can be defined simply in terms of pesticide volume reaching the intended target divided by total applied. Both theoretical investigations and field studies have demonstrated that pesticide application using liquid based sprays is at best only a few percent efficient (Hartley and Graham-Bryce, 1980; Pimentel and Levitan, 1986). Efficiency of application can be increased if droplet size is reduced, because increased droplet numbers increases the likelihood of impaction with an insect or weed surface. However, small droplets also lead to off target drift downwind of sprayed areas leading to the requirement of offset

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Nomenclature

ULV	Ultra Low Volume
EC	Emulsifiable Concentrate
LDP	Large Droplet Placement
HPN	Hydraulic Pressure Nozzle
GDM	Gaussian Diffusion Model
ICOB	In-Crop Offset Buffer
VMD	Volume Median Diameter
d	deposit (m^3/m^2)
k	constant = 0.4
h	release height (m)
q	line source (m^3/m)
i	turbulence intensity
x	downwind distance (m)
v	sedimentation velocity (m/s)
u	mean windspeed (m/s)
μm	micron, micrometre or 10^{-6} m
N^n	rotation rate (min^{-1}) to power n
V^v	airspeed (m/s) to power v
Q^q	flowrate (L/min) to power q
f	formulation constant ~3–6
E	energy per second (Js^{-1})
m	mass flow per second (kg s^{-1})
ρ	fluid density (kg m^{-2})
r_o	radius to tip of tooth on disc (m)
r_I	radius to inner wall of cup (m)
V_J	jet velocity (ms^{-1})
V_I	inner wall velocity (ms^{-1})
V_R	inviscid fluid radial velocity
f_B	breakup factor
ω	rotation rate (radians s^{-1})
C_D	drag coefficient
V_a	velocity of air relative to droplet (ms^{-1})
σ	surface tension of liquid (Nm^{-1})

buffer distances, in some instances of the order of several kilometres. Pollution from pesticides is exacerbated by two factors i) aerial transport of pesticide outside the intended target area, due to spray droplets being too small, ii) incorporation of pesticide directly into soil and groundwater rather than the crop canopy, due to spray droplets being too large. The former factor, commonly known as 'spray drift' can be reduced to manageable quantities by a number of methods, but with existing atomiser design, cannot be completely eliminated. This is because all present atomisation methods produce a range of droplet sizes, the finest ones of which are susceptible to drift.

Droplets produced by both conventional hydraulic nozzles and rotary nozzles can range in size from 10 μm to 3000 μm (Fig. 1). The distribution as depicted is schematic only, and is intended for the reader to place pesticide droplets within the context of other scientific fields. The range of droplet sizes experienced in irrigation would be represented by a bell curve to the right of that depicted in Fig. 1, and medical/atmospheric aerosols would form a bell curve to the left, for example.

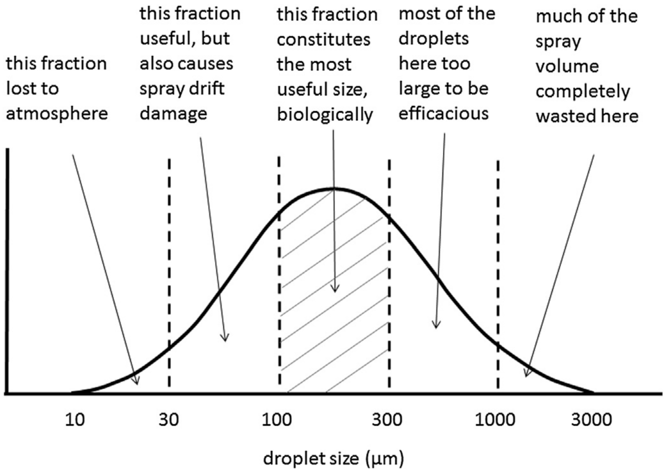

Fig. 1. Schematic illustration of the complete range of droplet sizes typically produced by most hydraulic and rotary cage nozzles, currently available for aerial and ground application of pesticides. The percentage of droplets between 100 and 300 μm, suggested here as the 'environmentally most useful size', often constitutes less than 20% of the total spray.

In pesticide application, droplets with diameters less than 100 μm upon release from the nozzle have low sedimentation velocity (25 cm/s) and shallow trajectory. These droplets, known as fines, can be effective against insect pests, but are also vulnerable to off target drift, evaporation and loss to atmosphere. Unless produced by air inclusion nozzles, droplets greater than 300 μm which contain most of the volume of conventionally applied sprays, have high sedimentation velocity (3 m/s) and steep trajectory, and are unlikely to strike a plant surface or pest (Spillman, 1987). Droplets greater than 300 μm become so few in number, that they are unlikely to strike an insect, or form reasonable coverage upon a leaf. Even within a dense crop canopy, coarse droplets may bounce from leaves or fragment, resulting in loss to ground, contributing to soil and/or groundwater pollution.

During the 1960s, rotary cage atomizers were successfully deployed in East Africa to apply small droplets (<100 μm) from aircraft, in very low volumes of oil carrier (Matthews, 1979). The application rate was typically less than 5 L per hectare, and this method of spraying is generally referred to as Ultra Low Volume (ULV). The ULV or sequential aerosol drift spraying technique has proven highly effective for locust and tsetse control in Africa (Johnstone et al., 1987), forestry applications (Richardson and Kimberley, 2010) and also for the control of *heliothis* and other insects in cotton (Woods et al., 1998).

Rotary cage units are capable of delivering large quantities of small droplets efficiently, enabling less active ingredient to be applied compared to conventional water based methods using emulsifiable concentrate (EC) formulations (Matthews, 1979; Woods et al., 2001). The pitch of the windmill blades used to drive the cage can be adjusted to produce a coarser droplet spectrum for larger volume water based fungicide or herbicide application. However, as the mode of atomisation is essentially that of fluid being smashed by a rotating cage, the width of the droplet spectrum at the larger droplet sizes (ie. lower rotational speed) is relatively wide, and similar to that produced by hydraulic nozzles. Also, with the tendency towards larger turbine powered aircraft with greater airspeeds, it can prove difficult to produce a spray with a Volume Median Diameter (VMD) greater than 200 μm, required for herbicide application.

For herbicide application purposes, a CDA based nozzle is therefore required to produce droplets between 100 and 300 μm, regarded as the biologically/environmentally optimum range (Fig. 1). These droplets are large enough not to drift long distances, and would be small enough to maintain high efficacy through good