DESIGN OF A SIMPLE DEVICE FOR LIMITING THE WIDTH OF THE DROPLET SIZE SPECTRUM FROM A HYDRAULIC FAN NOZZLE

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INTRODUCTION

Spray losses during application of pesticides to horticultural crops must be decreased to reduce the toxic load on the environment and to restrict the overkill of horticulturally important insects. Integrated control programs now being tested in commercial apple and peach orchards depend on precisely timed pesticide applications for success (8). It is accepted that to control spray requires some means of limiting the size of droplets emitted, that droplets below 80 μm drift excessively, and that small aqueous droplets evaporate rapidly under normal day-time conditions, (1, 6, 9, 10, 11, 12, 13). The aim, therefore, was to develop a practical field atomization-emission device which was simple, economical to produce, and which would restrict the size of droplets emitted to bounds considered optimum for both application efficiency and efficacy of deposit.

DESIGN LIMITATIONS

The following factors restricted the range of designs possible:

(i) The probability of impingement of a droplet decreases as its size is reduced (2).

(ii) Most atomization techniques designed to produce a narrow spectrum of droplet sizes are not satisfactory for wettable powders.

(iii) The mass flow rate of the spinning disc is too low for medium to high volume orchard applications.

(iv) Though foams are of some use for drift control, many are toxic to horticultural crops. It was decided, therefore, to develop a method using existing hydraulic nozzles for atomization and to separate and control the size of the droplets emitted by capturing those smaller than some predetermined diameter. This diameter will be dependent on ambient climatic conditions.

THEORY

Nomenclature

F_r = force in radial direction, (N);
$F\theta$ = force in angular direction, (N);
F_{dr} = drag force in r direction, (N);
$F_{d\theta}$ = drag force in θ direction, (N);
$a_r, a\theta$ = acceleration in radial and angular direction, (m/s^2) and (rad/s^2) respectively;
r = droplet's radial position, (m);
θ = droplet's angular position, (rad);
$\dot r, \dot\theta$ = droplet's radial and angular velocities (m/s) and (rad/s), respectively;
$\ddot r, \ddot\theta$ = droplet's radial and angular accelerations (m/s^2) and (rad/s^2), respectively;
m = mass of droplet, (kg);
w = weight of droplet, (N);
g = acceleration due to gravity, (m/s^2);
$C_{dr}, C_{d\theta}$ = drag coefficients in radial and angular directions;
ρ = weight density of air, (N/m^3);
A = cross-sectional area of droplet, (m^2);
v = kinematic viscosity of air, (m^2/s);
d = diameter of droplet, (m);
γ = specific weight of droplet, (N/m^3);
$\dot\theta_A$ = velocity of airstream in θ direction, (rad/s);
R_e = Reynolds number;
$V\theta$ = velocity difference between droplet and airstream in θ direction, (m/s).

With reference to Figure 1

$$\Sigma F_r = m\,a_r$$

and

$$\Sigma F\theta = m\,a\theta$$

but

$$a_r = \ddot r - r\,\dot\theta^2$$

and

$$a\theta = r\,\ddot\theta + 2\,\dot r\,\dot\theta$$

Summing forces in the r and θ direction yields

$$\Sigma F_r = F_{dr} + W\cos\theta = m(\ddot r - r\dot\theta^2) \quad \ldots\ldots (1)$$

$$\Sigma F\theta = F_{d\theta} - W\sin\theta = m\,(r\ddot\theta + 2\dot r\dot\theta) \quad \ldots\ldots (2)$$

but

$$F_{dr} = \frac{C_{dr}\rho A\dot r^2}{2g} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

From Clift et al. 1971 (3)

$$C_{dr} = [0.15\,(Re)^{0.687}\,(\frac{24}{Re}) + \frac{24}{Re}]$$

where

$$Re = \frac{\dot r d}{v}$$

$$\therefore C_{dr} = [3.6\,(\frac{\dot r d}{v})^{-0.313} + \frac{24v}{\dot r d}] \quad \ldots\ldots (4)$$

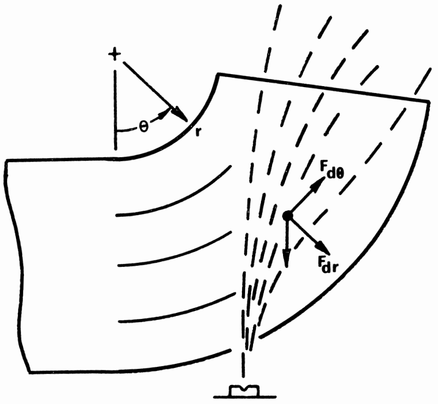

Figure 1. Diagram of duct showing the external forces acting on a droplet of spray material.

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Since

$$W = \frac{\pi d^3 \gamma}{6} \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

it follows by substituting in (1) that

$$[3.6\,(\frac{\dot{r}d}{\upsilon})^{-0.313} + \frac{24\upsilon}{\dot{r}d}]\,\frac{\rho\pi d^2\dot{r}^2}{8g}$$

$$+\frac{\pi d^3\gamma\cos\theta}{6} = \frac{\pi d^3\gamma}{6g}(\ddot{r} - r\dot{\theta}^2)$$

Dividing through by $\frac{\pi d^3\gamma}{6g}$ and transposing

$$\ddot{r} = r\dot{\theta}^2 + [3.6(\frac{\dot{r}d}{\upsilon})^{-0.313} + \frac{24\upsilon}{\dot{r}d}]\,\frac{0.75\rho\dot{r}^2}{d\gamma}$$

$$+ g\cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Similarly, in the θ direction

$$F_{d\theta} = \frac{C_{d\theta}\,\rho A V_{\theta}^2}{2g}$$

where

$$V_{\theta}^2 = (\dot{\theta}_A - \dot{\theta})^2$$

assuming

$$C_{d\theta} = [3.6\Big(\frac{(\dot{\theta}_A - \dot{\theta})d}{\upsilon}\Big)^{-0.313} + \frac{24\upsilon}{(\dot{\theta}_A - \dot{\theta})d}]$$

and substituting in (2) results in

$$[3.6\Big(\frac{(\dot{\theta}_A - \dot{\theta})d}{\upsilon}\Big)^{-0.313} + \frac{24\upsilon}{(\dot{\theta}_A - \dot{\theta})d}]$$

$$\frac{\rho\pi d^2(\dot{\theta}_A - \dot{\theta})^2}{8g} - \frac{\pi d^3\gamma\sin\theta}{6}$$

$$= \frac{\pi d^3\gamma}{6g}(r\ddot{\theta} + 2\dot{r}\dot{\theta}) \quad \ldots\ldots\ldots\ldots \quad (7)$$

Dividing through by $\frac{\pi d^3\gamma r}{6g}$ and rearranging gives

$$\ddot{\theta} = [3.6\Big(\frac{(\dot{\theta}_A - \dot{\theta})d}{\upsilon}\Big)^{-0.313} + \frac{24\upsilon}{(\dot{\theta}_A - \dot{\theta})d}]$$

$$\frac{0.75\,\rho(\dot{\theta}_A - \dot{\theta})^2}{dr\gamma} - \frac{g\sin\theta}{r} - \frac{2\dot{r}\dot{\theta}}{r} \quad \ldots\ldots \quad (8)$$

The assumptions of laminar and rotational flow in the duct, lack of a buoyant force acting on the droplets, and the absence of evaporation will introduce errors in equations 6 and 8. They are, however, considered to be reasonable approximations. The Runge-Kutta numerical method (7) was used to solve equations 6 and 8 on the computer and values for r and θ versus time were calculated. Initial conditions practical for an orchard sprayer design were selected. The time interval used in the iteration was 0.001 sec. The droplet trajectories are graphed in Figure 2 for four droplet diameters and indicate that droplet separation by this method is practicable.

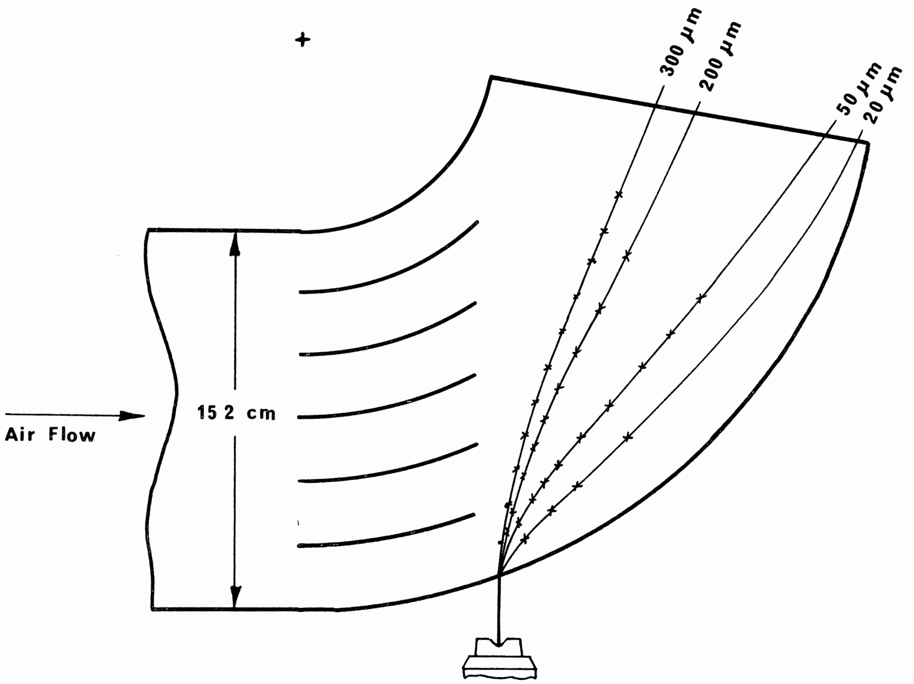

Figure 2. Results of the computer analysis of an emission control device for the experimental orchard sprayer showing size separation of droplets under medium air-velocity conditions. Air-flow 18.5 m/s, nozzle pressure 206.8 kPa, nozzle angular position $\theta = 20°$, injection angle 20°.

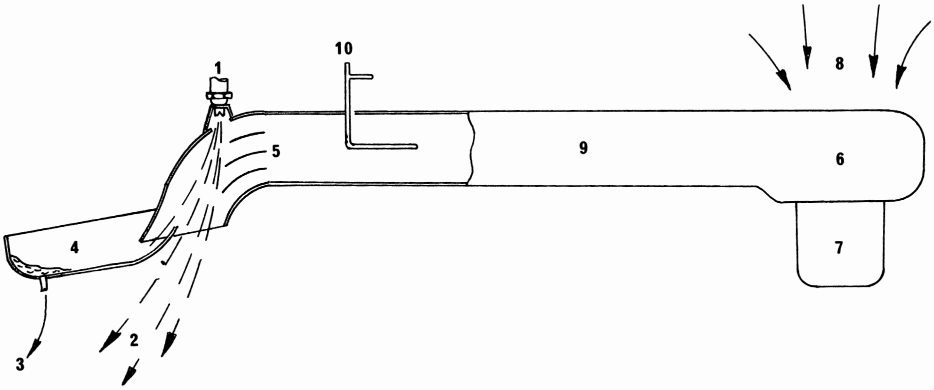

Figure 3. Schematic diagram of the laboratory model showing (1) fan nozzle; (2) emitted droplets and airstream; (3) separated spray material; (4) separating baffle; (5) airstream baffles; (6) blower; (7) blower motor; (8) air intake; (9) air duct; (10) pitotstatic tube for air velocity measurement.

TEST MODEL

A reduced scale laboratory test model was constructed and tested (Figure 3). Rigorous modelling techniques were not used in its design for it was only desired to check the practicality of the method. A Spraying Systems SS 800067 flat fan nozzle was used for atomization of water at 22°C and ·206.8 kPa. Droplets were collected by using the polybutene method of Fisher and Dougan (4) and droplet diameters were measured with a Vickers split-image eyepiece.

RESULTS AND DISCUSSION

The results of four tests of the laboratory device were graphed for the following duct center-line air velocities: 0, ca. 0.420 m/s, 0.660 m/s, and 1.040 m/s, at 40% RH and 23°C (Figure 4). The air flow at the point of injection was highly complex owing to the added turbulence from the guide vanes. The number median diameters of the respective droplet spectra are 54, 134, 123, and 158 μm. The separation device removed the small droplets from the spectrum and

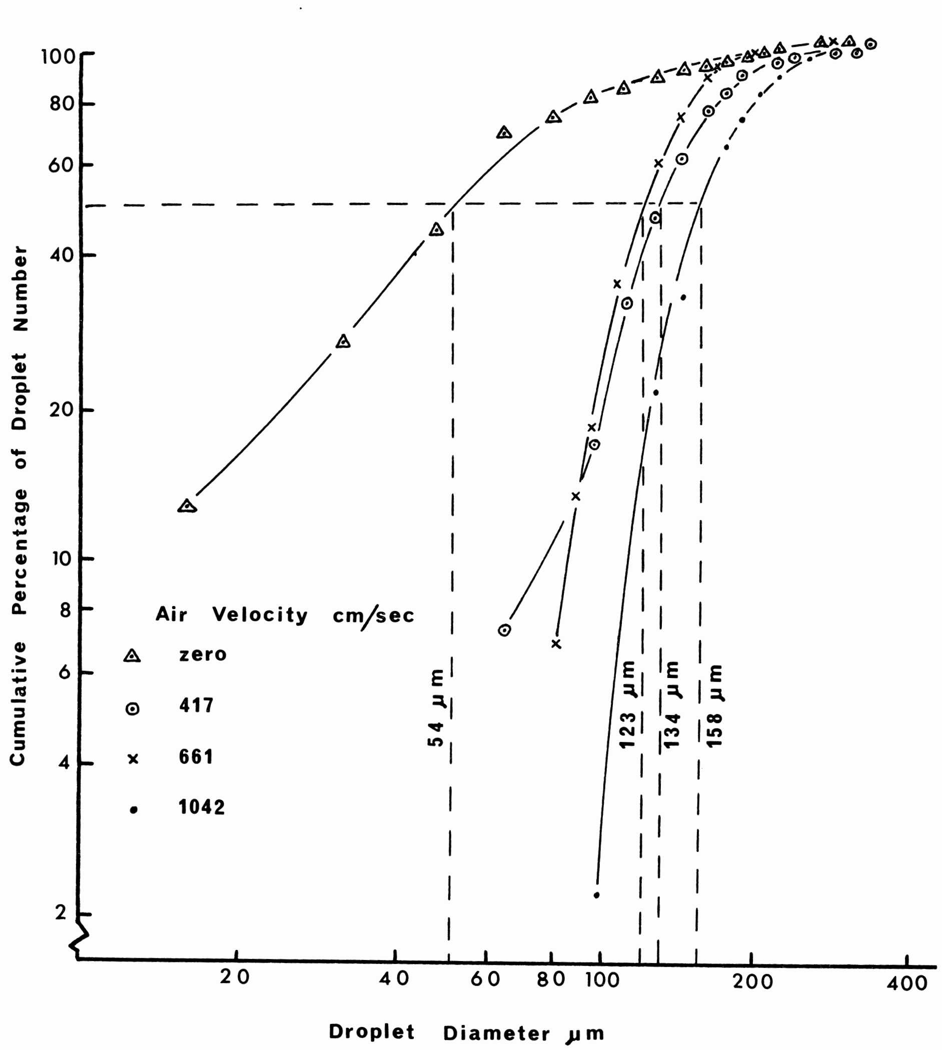

Figure 4. Laboratory test results showing degree of separation and modification of spray spectrum with four conditions of air flow. The number median diameters are noted.

the remaining droplets were projected by the airstream. At 1.040 m/s air velocity the smallest droplet in the spray deposit pattern had a diameter of 97 µm.

It is argued, often in support of ULV spray application, that droplets below 80 to 100 µm in diameter do not contribute significantly to pollution from spray operations (5). Small droplets, however, constitute a sizable portion in the spectrum of any sprayer. Moreover, if water-based, they are subject to disappearance from evaporation if smaller than 100 to 150 µm at the nozzles. Therefore, it is most important that they be contained or their emission restricted. Hooding sprayers to confine the spray on large orchard trees is not feasible but this selective emission device can prevent much of the spray drift by restricting the size of the droplets released. Impingement will be improved and savings in chemicals realized.

The method is practical and will form the basis of an orchard sprayer for experimental work in drift control and coverage assessment. A bank of nozzles will be used for atomization with the emitted spectra restricted to droplets between ca. 150 and 400 µm in diameter. Under extremely hot, dry conditions, droplets as large as 600 µm may be necessary. The retained droplets will be returned to a tank. Selection of the limits of droplet size will be based on prevailing ambient conditions.

SUMMARY

A method whereby the spray spectrum from a standard flat fan nozzle can be separated according to droplet size has been developed theoretically and analyzed on the computer using initial conditions practical for an orchard sprayer design. A laboratory model was constructed and tested and indicated the method was sound. The design is being incorporated in an experimental orchard sprayer for the study of drift control and coverage.

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