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RESEARCH NOTE

The Significance of Drop Velocity to the Determination of Drop Size Distributions of Agricultural Sprays

A. R. Frost*; J. R. Lake*

1. Introduction

There are many techniques available for sizing spray drops. A comprehensive recent review has been presented by Jones.[1] The purpose of this note is to consider the effects of drop velocities on the results from some of the more commonly used sizing techniques. In order to do this it is convenient to divide the techniques into two groups, according to whether a spatial or temporal sample is taken.

2. Spatial and temporal sampling

A spatial sample of spray is one which is taken instantaneously, for example from a photograph. It represents the numbers and sizes of drops in a field of view at a particular instant.

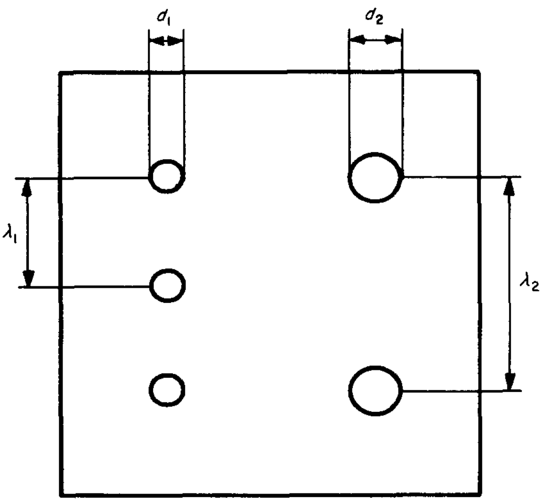

Fig. 1. Spatial sample

Fig. 1 is a representation of a simple example of a spatial sample. It contains images of drops of 2 diameters, d_1 and d_2, produced continuously at rates f_1 and f_2 moving vertically with velocities $\mathbf{v}_1$ and $\mathbf{v}_2$, with separations between successive drops of λ_1 and λ_2. As λ_1 is less than λ_2 more small drops are visible than large ones. Since $\lambda = \mathbf{v}/f$ the difference in the numbers of drops visible may be due to a difference in the frequencies of production of the 2 sizes of drop, a difference in their velocities, or both. The sample therefore contains no information about the relative numbers of each size of drop being produced and is biased in favour of slower moving drops.

*National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford

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A temporal sample of spray passes through, or impinges on, a plane normal to the direction of flow of the spray, over a period of time. By this definition a temporal sample is obtained if, for example, a collecting surface is exposed to the spray. Such a sample would be a true representation of the relative numbers of the various sizes of drop passing through the sampling area or being produced by the atomizer if no evaporation or coalescence of drops occurs.

For the majority of uses of drop size information a temporal sample is of greater relevance than a spatial one. The latter would suffice if all that is required is a knowledge of the range of sizes of drop present in the spray, but in general it is necessary to know the relative numbers of the various sizes.

A spatial distribution can be transformed to a temporal one provided the drops are moving in a continuous stream with known velocities. In this case the number of drops in each size class in the spatial distribution is multiplied by the average velocity of the drops in the class to obtain the temporal distribution. The average velocities may be measured for example by double exposure photography.[2]

However, Clark and Dombrowski[3] have pointed out that atomization often occurs in a periodic rather than a continuous manner. The sprays from hydraulic nozzles for example show periodicity. In such cases the above simple transformation from a spatial to temporal sample is not valid. A valid transformation would require a measure of the periodicity as well as measures of drop velocities.

Spatial sampling techniques in current use include:

(i) photography,[2-4]
(ii) holography[5] and
(iii) light scattering by a field of drops.[6-8]

Temporal sampling techniques in current use include:

(i) collecting surfaces[9,10] and cells,[11]
(ii) light scattering by single drops[12] and
(iii) optical array shadowing.[13]

3. The velocities of drops in agricultural sprays

3.1. *Hydraulic pressure nozzles*

This type of atomizer forms spray by passing liquid, under pressure, through an orifice. A sheet of liquid is formed which expands and breaks up into drops, ranging in size typically from one or two microns to several hundred microns in diameter. Table I shows the mean velocities of three sizes of drop from a typical agricultural nozzle measured using double exposure spark photography,[14] at 3 distances below the nozzle orifice.

TABLE I

Mean drop velocities (m/s) from Spraying Systems Company 8002 nozzle at 200 kN/m^2 with 95% confidence limits; sheet velocity 18·5 m/s

Distance below orifice (mm)	*Drop diameter (μm)*		
	50	*100*	*200*
50±10	8·2±1·1	13·0±1·1	17·1±1·0
100±10	6·4±0·9	10·8±1·0	15·0±0·5
1000±10	1·4±0·1	1·6±0·2	2·2±0·1
Terminal velocity (m/s)	0·07	0·25	0·65

The velocity of a drop at any given distance below the orifice depends upon the velocity of the liquid sheet and on the effects of gravitational and aerodynamic forces. The aerodynamic forces are difficult to calculate because air is entrained in the spray by the moving liquid and so the relative velocity between the air and the drop is uncertain. The values presented in Table I are therefore of little value in predicting what would happen if a different type of nozzle or different operating conditions were used. However they do indicate that it is very likely that there will be significant differences in the velocities of different sizes of drop at a given distance from the nozzle. Therefore the validity of drop size information obtained using any of the velocity dependent sizing techniques must be seriously questioned in the absence of drop velocity measurements for the particular nozzle and operating conditions being studied.

It may be thought that positioning the sampling area sufficiently close to the nozzle would ensure that all the drops had the same velocity (that of the liquid sheet). The problem here is in ensuring that atomization is complete by the time the drops reach the sampling area. Fragments of the liquid sheet can subdivide beyond the perimeter of the sheet and Table I indicates that small drops will have decelerated significantly in the distance over which this subdivision occurs.

Alternatively the sampling area may be positioned sufficiently far from the nozzle to enable terminal velocity for all the drop sizes present to be assumed. Such an approach would require still air conditions in the vicinity of the sampling area (which would almost certainly not be the case due to the movement of the spray) since the terminal velocities of the small drops are so low (e.g. 0·003 m/s for a 10μm diameter drop).

4. Rotary atomizers

This type of atomizer produces spray by feeding liquid onto the centre of a rotary disc or cup causing drops to be formed either directly from its edge, or by the disintegration of liquid ligaments formed at the disc edge.[15] If the atomizer is rotating about a vertical axis, the horizontal component of the velocity of the drops decays from an initial value, equal to the peripheral velocity of the atomizer, to zero at some distance from the atomizer edge. The rate of decay of the velocity depends upon the size of drop. The situation is complicated by air movements due to the rotation of the atomizer and the movement of the spray.

Table II shows the mean horizontal components of velocities of three sizes of drop measured at three different radial distances. Two types of rotary atomizers were used with vertical axes and

TABLE II

Mean drop velocities (m/s) from plain disc[15] with peripheral velocity 11·2 m/s with 95% confidence limits

Radial distance from drop to disc edge (mm)	*Drop diameter (μm)*		
	50	*100*	*200*
17·5±2·5	7·9±0·3	9·2±0·4	10·6±0·3
27·5±2·5	6·2±0·5	8·6±0·5	9·5±0·6

Mean drop velocities (m/s) from Micron Sprayers Limited Micromax disc, peripheral velocity 17·8 m/s, with 95% confidence limits

Radial distance from drop to disc edge (mm)	*Drop diameter (μm)*		
	50	*100*	*200*
17·5±2·5	5·9±1·6	13·7±0·6	15·4±1·1
27·5±2·5	2·8±1·8	11·9±0·8	14·9±1·0

both producing drops from ligaments. Table II shows differences between the velocities of different sizes of drop, which would lead to significant errors if velocity dependent drop sizing techniques were used.

The vertical component of velocity of a drop from an atomizer rotating about a vertical axis is initially zero and increases to terminal velocity, and the comments above regarding sampling at terminal velocity from a hydraulic nozzle apply.

5. Conclusions

In making measurements of the drop size distribution of sprays it is essential to know whether the technique being used gives results which are dependent on the velocities of the drops.

Techniques that use spatial samples give results which are velocity dependent. They indicate the range of sizes present but not their relative numbers. Techniques using temporal samples are independent of velocity.

Significant differences have been measured in the velocities of different sizes of drop produced by both hydraulic pressure nozzles and rotary atomizers. If these velocity differences were ignored, size distribution measured by techniques producing spatial samples would be in error.

A spatial sample may be transformed into a temporal one if the drops are moving through the sampling area in a continuous manner with known velocities. If the spray formation process is periodic, as in the case with hydraulic pressure nozzles, a measure of periodicity as well as velocity would have to be included in the transformation.

To avoid such complications it is therefore recommended that techniques using temporal samples should be used to determine the drop size distributions of agricultural sprays.

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