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Droplet Size characterization of agricultural sprays using laser diffraction

Aditya Sirmour and Ajay Verma

Abstract
Accurate spray characterization helps to better understand the pesticide spray application process. The goal of this research was to present the proof of principle of a droplet size and velocity measuring technique for different types of hydraulic spray nozzles using laser diffraction method. Control of agricultural spray deposition is vital if pesticides and other agrochemicals are to be delivered safely and effectively to the intended target. One of the most significant parameters in controlling the behaviour of these sprays is the droplet size. Research has shown that the spray droplet size, and the factors which affect it, is one of the most important variables affecting spray deposition levels downwind of the application area (spray drift). The droplet size also defines how the spray is accumulated by the target species.
A variety of different particle sizing techniques have been used to characterise agricultural sprays in the past. Of those available, laser diffraction provides a flexible and rapid method for the assessment of the delivered particle size. Modern laser diffraction equipment allows data acquisition rates of up to 2500Hz to be achieved (one measurement every 0.4ms), permitting both the average particle size delivered by the spray system and the spray dynamics to be assessed. This allows for an increased understanding of the atomisation process and the effect of formulation changes on the delivered particle size, leading to improved efficiency of delivery to the intended target.

Keywords: Droplet Size Characterization, Laser Diffraction and Agricultural Sprays

Introduction
The droplet size and size distribution of the droplets produced by nozzle systems are important in defining the performance of agrochemical application systems, both in terms of treatment efficiency and environmental impact. The use of fine particle sprays can lead to increased surface deposition on leaves. However, fine particles are more likely to be subject to spray drift away from the target area (the settling velocity of particles varies approximately as the square of the droplet's diameter). The use of coarse particle sprays can help eliminate drift and can also penetrate into the plant canopy, thus allowing the lower parts of the target to be treated. However, the risk of soil contamination and run-off becomes high. Thus, the particle size must be controlled in order to provide the correct performance, dependent upon the target species and the environmental conditions. The most commonly used parameter of droplet size in agricultural spraying is the volume mean diameter (VMD). The VMD is the diameter which divides the spray into equal halves by volume, one half containing droplets smaller than that diameter and the other half, larger droplets. A second parameter is the number mean diameter (NMD), which is the diameter that divides the spray into equal numbers of smaller and larger droplets. A single parameter is inadequate to describe the spray since a few large droplets can account for a large proportion of the volume of a spray containing many small droplets. The ratio of VMD: NMD can be used to express the uniformity of the spray. Both parameters were used in the droplet size analysis for the selection of correct nozzle for effective spray application.

Spray nozzle selection
It is important to select a nozzle that develops the desired spray pattern. The specific use of a nozzle, such as broadcast application of herbicides or insecticides on row crops, determines the type of nozzle needed. The nozzle is a major factor in determining the amount of spray applied to an area, uniformity of application, coverage obtained on the target surface, and amount of potential drift. In spraying systems, nozzles break the liquid into droplets and form the spray

pattern. Nozzles determine the application volume at a given operating pressure, travel speed, and spacing. A wide range of nozzles are available, producing plumes of different shapes (flat fan, hollow cone) and droplets of different sizes. The importance of the nozzle has prompted the development of a classification scheme by the ASAE standard S.5721.1 (2009). This scheme aims to aid in the selection of the most appropriate spray size and distribution required for particular products, and to do this in a way that is easily communicated to the user. In this way, it is hoped that the use of sprays that may be environmentally unacceptable.

Spray Particle Size Measurements

A variety of different particle sizing techniques have been used for the characterization of agrochemical sprays in the past. These vary from those based on intrusive collection methods, to imaging techniques and those using laser light scattering or absorption. Of those available, laser diffraction provides a flexible and rapid method for the assessment of the delivered particle size. The Malvern Particle Analyzer, which is considered a spatial sampling device, utilizes the fact that a spray drop will cause laser light to scatter through an angle dependent on the diameter of the drop (Fig. 1). The scattered light intensity is measured using a series of semicircular photo diodes. Theoretically, the distance of the individual photo diodes from the centre line of the laser and the light intensity functions are all that are needed to calculate the drop size distribution. A curve-fitting program is used to convert the light intensity distribution into any of several empirical drop size distribution functions. Since the Malvern has some self-diagnostics, potential sources of error are easier to identify. The instrument must be aligned and calibrated periodically using reticule slides with known etched drop distributions.

Technical background

A 4mW helium-neon laser produces a beam which is spatially filtered, then expanded and collimated in a beam expander to give a uniform 632.8 nm output beam. The spray is passed through the beam, which is diffracted and focused by a Fourier transform lens onto a multi-element silicon photo-detector placed at the focal plane of the lens. The diameter of the diffraction pattern is inversely proportional to the diameter of the droplet, and, since parallel light always focuses on its axis, the movement of droplets through the beam will not affect the diffraction pattern. The photo detector consists of 36 log-spaced silicon diode detector arrays, each of which is most sensitive to a particular droplet size. The light energy falling on any element of the detector is then the sum of the contributions from all the droplets in the spray cloud. The output from each element is converted to a ten bit number which is stored in the computer as a measurement of the light energy distribution across the photo-detector.

Working of Malvern Spraytec instrument

The "Malvern-Spraytec" system measures spray droplet and particle size distributions using the technique of laser diffraction (Fig.1). This requires the angular intensity of light scattered from a spray to be measured as it passes through a laser beam. Detecting optics in the receiver module detects the light diffraction pattern produced by the spray, converting the light detected into electrical signals. The signal is processed by analogue and digital electronics boards. This data is then analyzed to calculate the size of droplets and created the scattering pattern.

The recorded scattering pattern is then analyzed using an appropriate optical model to yield a size distribution. The angular range over which scattering measurements are made has been optimized within the spraytec to ensure that poly-disperse size distributions are fully resolved. In addition, a maximum data acquisition rate of 10 kHz ensures that any temporal fluctuations in the spray particle size are detected and understood.

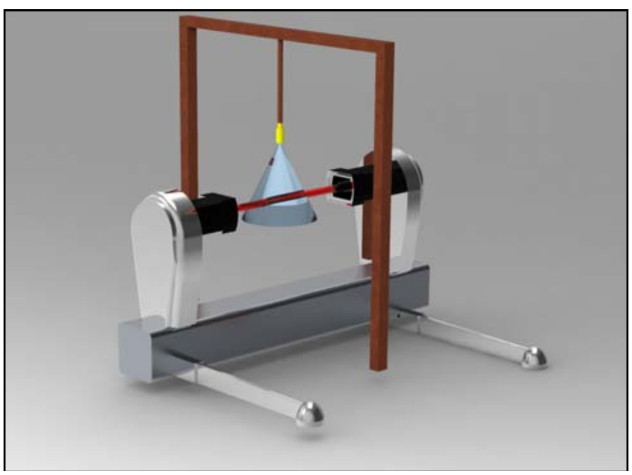

Fig 1: Diagram of Malvern Spraytec instrument

- Light from the laser (1) is scattered by the spray droplets (3) (Fig. 2).
- The laser beam is expanded by the collimating optics (2) to provide a wide parallel beam.
- The scattered light is focused by a focusing lens (4) in a Fourier arrangement and picked up by the detector array (5).
- Unscattered light is focused by the focusing lens (4), so that it passes through the pinhole at the centre of the detector array. This is measured by the beam power detector to give the light transmission (Fig. 2).
- The angle at which a particle diffracts light is inversely proportional to its size. The detector array is made up of over 30 individual detectors, each of which collects the light scattered by a particular range of angles. There is a data channel for each of these. Measuring the angle of diffraction determines the size of the particle, as shown in the following diagram (Fig. 2).

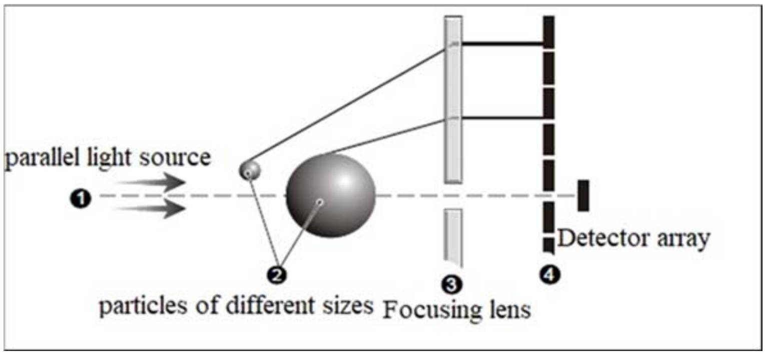

Fig 2: Labelled diagram of Malvern Spraytec

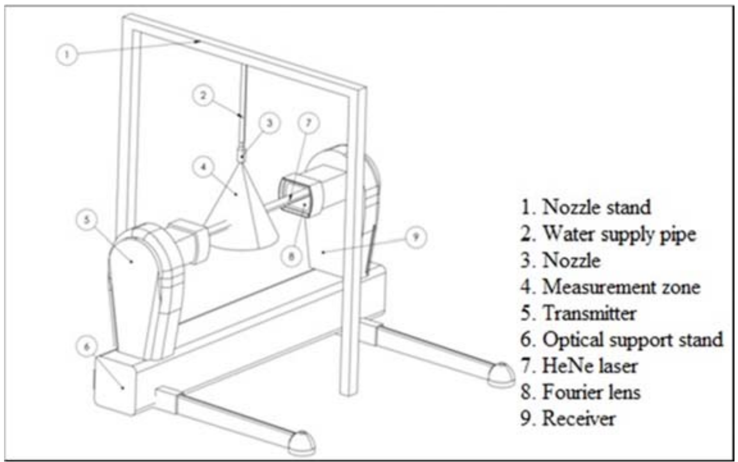

Fig 3: Spraytec instrument laser droplet size analysis- CIAE, Bhopal

Modelling Droplet Scattering

The scattering from droplets containing bubbles can be modelled using the Mie scattering model for layered particles. This model is available within Malvern Instrument's Zetasizer software and allows the scattering intensity at any angle to be predicted for droplets containing a second phase. The scattering intensity values can then be input into Malvern Instrument's laser diffraction software in order to calculate the associated size distribution using a Mie model which assumes that only as single droplet phase is present.

Mie theory predicts that refraction within the droplet only contributes significantly to the observed scattering when the droplet diameter is less that 40l. This relates to a limit of around 25 to 30 microns in the case of the Spraytec system, which uses a 670nm laser source. Calculations of the scattering from bubble-filled droplets were therefore limited to fewer than 25 microns. Fig. 4 shows the distribution used in this study, as calculated by the Malvern laser diffraction software for the case where no bubbles were present within the droplet phase

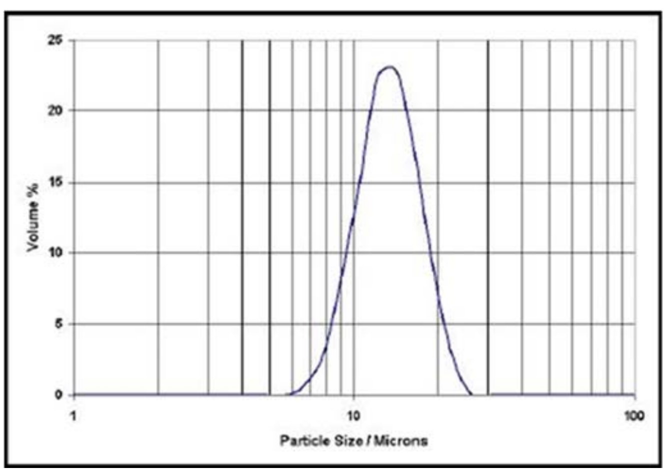

Fig 4: Size distribution used in the polydisperse distribution calculations.

The scattering patterns calculated as a function of bubble size for the polydisperse distribution defined above are shown in Fig. 5.

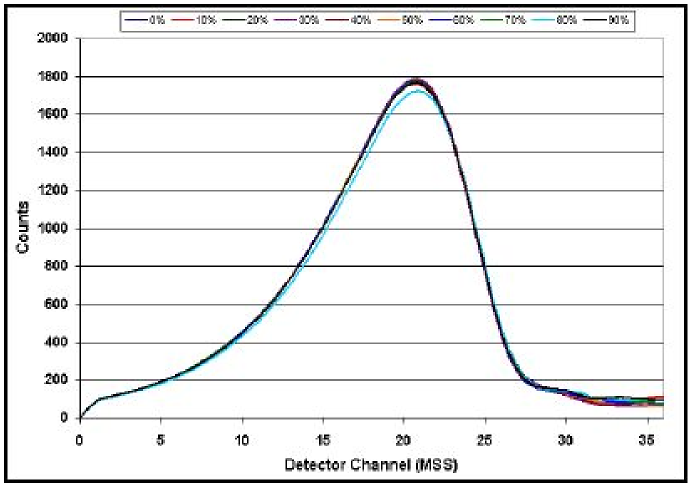

Fig 5: Scattering patterns calculated for polydisperse distribution

Table 1: Particle size distribution statistics reported for droplets

Size (µm)	% V <	% V	Size (µm)	% V <	% V	Size (µm)	% V <	% V
1.14	0.00	0.00	15.46	0.02	0.02	209.85	50.98	7.61
1.30	0.00	0.00	17.62	0.07	0.06	239.08	58.40	7.42
1.48	0.00	0.00	20.07	0.18	0.10	272.38	65.45	7.05
1.68	0.00	0.00	22.86	0.33	0.15	310.32	71.98	6.54
1.92	0.00	0.00	26.05	0.52	0.19	353.54	77.90	5.91
2.19	0.00	0.00	29.68	0.73	0.21	402.79	83.07	5.18
2.49	0.00	0.00	33.81	0.96	0.22	458.89	87.43	4.35
2.84	0.00	0.00	38.52	1.19	0.23	522.80	90.89	3.46
3.23	0.00	0.00	43.89	1.46	0.27	595.62	93.45	2.56
3.68	0.00	0.00	50.00	1.84	0.38	678.58	95.16	1.71
4.20	0.00	0.00	56.96	2.46	0.62	773.10	96.13	0.98
4.78	0.00	0.00	64.90	3.51	1.05	880.78	96.56	0.42
5.45	0.00	0.00	73.94	5.21	1.70	1003.46	96.64	0.09
6.21	0.00	0.00	84.23	7.77	2.57	1143.22	96.64	0.00
7.07	0.00	0.00	95.97	11.38	3.60	1302.46	96.64	0.00
8.06	0.00	0.00	109.33	16.10	4.72	1483.87	96.64	0.00
9.18	0.00	0.00	124.56	21.87	5.77	1690.55	96.64	0.00
10.46	0.00	0.00	141.91	28.52	6.65	1926.01	98.84	2.20
11.91	0.00	0.00	161.68	35.79	7.27	2194.28	100.00	1.16
13.57	0.00	0.00	184.20	43.37	7.58	2499.90	100.00	0.00

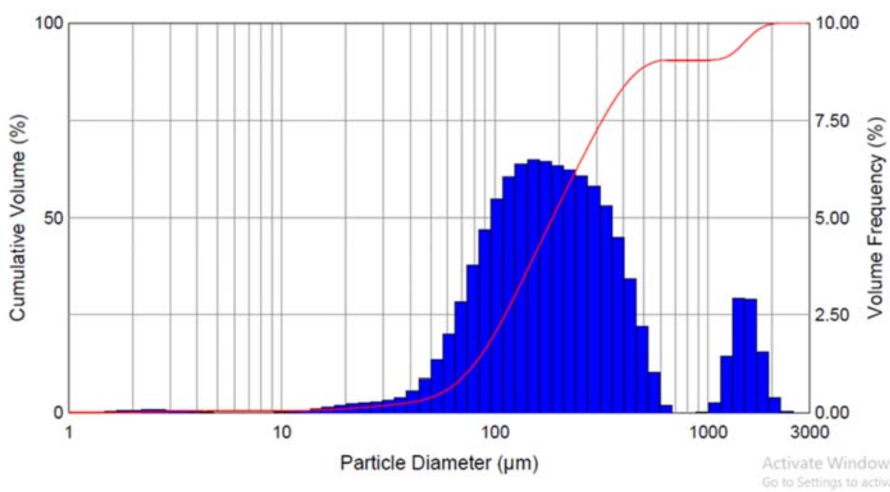

Fig 6: Particle size distribution histogram report for droplets

Conclusions

This paper has covered the importance of droplet size in agricultural spraying. The efficacy of crop coverage, the occurrence of soil run-off and spray drift is all dependent on the droplet size. The droplet size must therefore be tailored to the target and spraying conditions. Hence it is essential that the performance of agricultural nozzles is well understood. The Spraytec has been used to characterize the reference nozzles which define the ASAE S.5721.1 standard (2009) size categories. The technique of laser diffraction provides a robust means of measuring the particle size of agrochemical sprays, allowing both the spray dynamics and the spray-plume profile to be assessed. The results obtained using laser diffraction techniques have, in the past, been questioned due to the unknown effect of air inclusions on the obtained results.

References

1. Azimi AH, Carpenter TG, Reichard DL. Nozzle spray distribution for pesticide application. Trans. ASAE. 1985; 28:1410-1414.
2. Zhu H, Rowland DL, Dorner RC, Sorensen RB. Influence of plant structure, orifice size and nozzle inclination on spray penetration into peanut canopy. Trans. ASAE. 2002; 45:1285-1301.
3. Foqué D, Nuyttens D. Effects of nozzle type and spray angle on spray deposition in ivy pot plants. Pest Manag. Sci. 2011; 67:199-208.
4. Rhodes MJ. Introduction to Particle Technology, 2nd ed.; John Wilery and Sons Inc.: Hoboken, NJ, USA, 2008.
5. Nuyttens D. Drift from Field Crop Sprayers: The Influence of Spray Application Technology Determined Using Indirect and Direct Drift Assessment Means. Ph.D. Thesis, KU Leuven, Leuven, Belgium, 2007.
6. Nuyttens D, De Schampheleire M, Verboven P, Brusselman E, Dekeyser D. Droplet Size and Velocity Characteristics of Agricultural Sprays. Trans. ASAE. 2009; 52:1471-1480.
7. Stainier C, Destain MF, Schiffers B, Lebeau F. Droplet size spectra and drift effect of two phenmedipham formulations and four adjuvants mixtures. Crop Prot. 2006; 25:1238-1243.
8. Teske ME, Thistle HW, Hewitt AJ, Kirk IW. Conversion of droplet size distributions from PMS Optical Array Probe to Malvern Laser Diffraction. At. Sprays. 2002; 12:267-281.
9. Hijazi B, Decourselle T, Vulgarakis Minov S, Nuyttens D, Cointault F, Pieters JG, Vangeyte J. The Useof High-Speed Imaging System for Applications in Precision Agriculture. In New Technologies: Trends, Innovations and Research; Constantin, V., Ed.; Intech: England, UK, 2012.
10. Lecuona A, Sosa PA, Rodriguez PA, Zequeira RI. Volumetric characterization of dispersed two-phase flows by digital image analysis. Meas. Sci. Technol. 2000; 11:1152-1161.
11. Graßmann A, Peters F. Size measurement of very small spherical particles by Mie Scattering Imaging (MSI).Part. Part. Syst. Charact. 2004; 21:379-389.
12. Bachalo DW. Dual beam light-scatter interferometry. Appl. Opt. 1980; 19:363-370. [PubMed]
13. Kannaiyan K, Sadr R. Effect of fuel properties on spray characteristics of alternative jet fuels using global sizing velocimetry. At. Sprays. 2014; 24:575-597.
14. Ju D, Shrimpton JS, Hearn AA, Multi-Thresholding Algorithm for Sizing out of Focus Particles. Part. Part. Syst. Charact. 2012; 29:78-92.
15. Berg T, Deppe J, Michaelis D, Voges H, Wissel S. Comparison of Particle Size and Velocity Investigations in Sprays Carried out by Means of Different Measurement Techniques; ICLASS: Kyoto, Japan, 2006.
16. Kashdan JT, Shrimpton JS, Whybrew AA. digital image analysis technique for quantitative characterisation of high-speed sprays. Opt. Lasers Eng. 2007; 45:106-115.
17. Kim KS, Kim SS. Drop sizing and depth-of-field correction in TV imaging. At. Sprays 1994; 4:65-78.
18. Malot H, Blaisot JB. Droplet size distribution and sphericity measurements of low-density sprays through image analysis. Part. Part. Syst. Charact. 2000; 17:146-158.