COMPARISON OF DROP SIZE DATA FROM GROUND AND AERIAL APPLICATION NOZZLES AT THREE TESTING LABORATORIES

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Spray drop size is a critical factor in the performance of any agrochemical solution and is a function of spray solution, nozzle selection, and nozzle operation. Applicators generally select a particular nozzle based on the drop size reported by manufacturers and researchers. Like most population sampling methods, the accurate measurement of spray drop sizing is a function of sampling methodology, accuracy of the measurement, and inferences about a total population from a subset. Studies were conducted to determine the repeatability and accuracy of spray drop size from a standardized set of spray nozzles at three different application technology research laboratories (USDA-ARS in College Station, Texas; University of Nebraska-Lincoln in North Platte, Nebraska; and University of Queensland, Gatton in Gatton, Australia). To minimize differences in drop size measurements between laboratories, the same set of nozzles was used at each location. The three laboratory measurements of drop size varied by less than 5% except for the measurement of the very largest drops in a spray plume. Day-to-day differences in drop size measurements within each lab were also found to be around 5%. This work shows that through careful monitoring of spray pressure, air speed, and measurement distance, very close agreement in drop size measurements can be obtained between different facilities.

KEY WORDS: *spray atomization, laser diffraction, drop size, agricultural sprays, application technology*

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1. INTRODUCTION

With any agrochemical spray application, the drop size characteristics of the spray drive both on- (Himel, 1969; Salyani, 1988; Smith et al., 2000; Fritz et al., 2007) and off-target movement and deposition (Bouse, 1994; Hewitt, 2000; Hewitt et al., 2002). Being able to accurately measure spray drop size resulting from different application technologies is a critical part of evaluating their performance and determining optimal operational parameters. There are a number of different systems and methods available to measure the size characteristics of a spray, but the type of system (Dodge, 1987) and the methods used (Hammond, 1981; Tishkoff, 1984) will influence the final results. The drop size data collected for the current experiment were all obtained using laser diffraction instruments, which is by definition a spatial sampling method. Drop sizing methods typically fall into two major classes, spatially and temporally derived data. The characterization between these two classes is largely based on the method by which each class measures the drop sizes in a spray with inhomogeneous velocities (Lefebvre, 1989). Further discussions of these two classes can be found elsewhere (Dodge et al., 1987; Young and Bachalo, 1988; Levebvre, 1989; Arnold, 1990).

To compensate for biases amongst measurement techniques and allow data comparisons between labs, a number of standards and methods have been proposed. The Brighton Crop Protection Conference (BCPC) (Doble et al., 1985), the American Society of Agricultural and Biological Engineers (ASABE) (ASAE, 2009), and the American Society for Testing and Materials (ASTM, 2009; ASTM 2010) noted that there were differences between methods, which should be documented, or proposed relative classification schemes that classified an unknown nozzle against a set of curves developed from established reference nozzles. Hewitt (2008) established a similar set of reference nozzles and classification curves for testing aerial nozzles at higher coaxial air velocities. The BCPC and ASABE standards require labs to generate sets of reference curves to which tested nozzles are compared and given a classification rather than involving actual numerical drop size data. However, the numerical size data are being reported by many labs used as indicators of potential drift and for comparison of potential drift reduction from new technologies, without citing the reference classification scheme.

ASTM Standard E2798 (2011) was developed using drop sizing evaluations conducted at multiple labs, each different in setup and methods but all using laser diffraction, for a series of nozzles and spray formulations (Elsik, 2011). Coaxial air flows ranged from 0.7 m/s (1.6 mph) or less to 3 m/s (6.7 mph), with measurement distance not reported for all labs. Consistently larger drop size data were reported for labs with higher coaxial air flow velocities, agreeing with the results of previously mentioned studies and specifically noted as part of a Spray Drift Task Force (SDTF) study (SDTF, 1997), which noted that the spatial bias from laser diffraction results diminishes with higher airflows.

The SDTF study compared three nozzles at two pressures across air speeds ranging from 0 to 54 m/s (0 to 121 mph) (SDTF, 1997). They found large spatial biases at air speeds below 3 m/s (6.7 m/s) and similar drop sizes measured at 8 and 36 m/s (18 and 80 mph) (SDTF, 1997). These spatial biases were minimal at air stream velocities from 13 to 27 m/s (30 to 60 mph) as a result of the air stream velocity being close to the nozzle exit velocities (SDTF, 1997). The final conclusion of this work was that air stream velocities below 8–11 m/s (18 to 25 mph) should not be used with spatial sampling methods as a result of the large bias in oversampling the smallest drop diameter portion of the spray (SDTF, 1997). Teske et al. (2002) noted that for atomization studies conducted with nozzles in air streams with velocities associated with aerial application conditions, this spatial bias error is only 2–5 percent. In an effort to develop a standard that address all of the concerns surrounding the use of laser diffraction for measuring drop size from agricultural sprays, a draft ASTM standard is being proposed (ASTM, 2011), which provides guidance on measurement procedures including measurement distance from the nozzle with respect to spray drop velocity specifying a need for drops to have accelerated to 90% of the air stream velocity to avoid spatial bias.

As part of establishing standard methods and practices to alleviate the spatial bias with the current facilities, the USDA-ARS-Aerial Application Technology lab in College Station, Texas undertook a series of studies examining drop size and velocities from a series of nozzles at multiple spray pressures with measurements being made at multiple downstream measurement distances and coaxial air velocities.

It was found the overall results aligned very closely with previous work reported earlier, with standard methods for typical nozzles being established for both ground and aerial spray nozzles using laser diffraction (unpublished data). Ground nozzle evaluations required a measurement distance from nozzle exit to line of measurement of 30.5 cm (12 in) with a coaxial air velocity of 6.7 m/s (15 mph) (the maximum velocity for the facilities). Aerial nozzle evaluations required a measurement distance from the nozzle exit to the line of measurement of 45.7 cm (18 in) for all air speeds tested. Spatial biases at these settings were found to be less than 9% and typically 3–4% for ground nozzle testing and less than 5% for aerial nozzle testing.

The objective of this work was to use these established standard methods and evaluate a series of ground and aerial nozzles at three cooperating laboratories and compare the drop size data obtained at each.

2. METHODS

2.1 Test Facilities

A description of each location's testing facility, as well as the protocol used in this study, is described in following. It should be noted that the same person conducted or oversaw the testing at all three facilities.

2.1.1 USDA ARS — Ground Nozzle Testing

All ground nozzle testing conducted by the United States Department of Agriculture, Agricultural Research Service (USDA ARS) Aerial Application Technology (AAT) laboratory (heretofore referred to as ARS) was done in a low wind speed tunnel located in College Station, Texas, USA. The tunnel is 1.2 × 1.2 m (4 × 4 ft) square by 9.8 m (32 ft) long with an operational air speed range of 0–8 m/s (0–18 mph). The outlet section of the tunnel was funneled through a forced impaction scrubber system that uses an assisted suction fan to maintain air velocity through the filter. The tunnel had an open break at 7.3 m (24 ft) such that a gap of approximately 0.6 m (2 ft) was present. The laser diffraction system was inserted into this gap for measurement purposes. Concurrent air velocity of 6.7 m/s (15 mph) was used for all testing. The nozzle was positioned to spray horizontally, parallel to the airflow with the spray fan perpendicular to the laser beam. The nozzle body was secured on a vertical traverse allowing for the full spray cloud to be traversed through the laser. Nozzles were plumbed (minimum 6.4 mm (0.25 in) i.d. tubing and fittings) to 19 L (5 gal) stainless steel pressure tanks, which were pressurized using an air compressor. A pressure regulator was used to adjust and maintain pressure that was measured using an electronic pressure transducer (Model PX409-100GUSB, Omega Engineering, Inc., Stamford, CT) and was positioned 20 cm (7.8 in) from the nozzle outlet.

A Sympatec HELOS laser diffraction system was used for ground nozzle drop sizing. The R7 lens, which has a dynamic sizing range of 18–3500 μm divided across 32 size bins, was used. For all testing, a forced stability of 1 muted the upper size bin. It was ensured during all measurements that no drop size data were measured within three bins of the upper channel. Measurement distance between nozzle outlet and laser beam was set at 30.5 cm (12 inches). Each measurement replication consisted of one full vertical traverse of the spray plume with the nozzle being traversed vertically upward at a rate of 6.4 cm/s (2.5 in/s). Sufficient replications were made to insure that the standard deviations of $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ were all within ±5% of the means with a minimum of three replications being made. Averages and standards deviations of $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ and percent volume less than 100 μm were determined.

2.1.2 USDA ARS — Aerial Reference Nozzle Testing

Aerial reference nozzle testing conducted by the ARS was done in the laboratory's high-speed tunnel. The tunnel has an outlet section of 0.3 × 0.3 m (1 × 1 ft) and the plumbed spray boom mounted on a vertical linear traverse on the immediate outlet of the tunnel section. Released spray material was carried through a larger (1.2 × 1.2 m × 2.4 m (4 × 4 × 8 ft) tunnel section into a 4.8 × 4.8 m (16 × 16 ft) scrubber section to remove spray effluent. The operational air speed ranges from 6.7 to 98 m/s (15 to 220 mph). For this study, an air speed of 51 m/s (115 mph) was used based on the suggested aerial reference nozzle scheme reported by Hewitt (2008). Measurements were made 45.7 cm

(18 in) downstream of the nozzle outlet with the spray plume being traversed through the measurement area, vertically, at a rate of 6.4 cm/s (2.5 in/s). Spray nozzles were mounted on the boom similar to how they would be configured on an aircraft with the boom plumbed to a pressurized spray container. The pressure was controlled via a pressure regulator and measured using an electronic pressure gauge (PX409-100GUSB, Omega Engineering, Stamford CT) that was positioned within 20 cm (8 in) of the nozzle outlet. The same Sympatec laser diffraction system was used, at the same settings, as described in the ground nozzle testing section.

2.1.3 University of Nebraska-Lincoln — Ground Nozzle Testing

All ground nozzle testing conducted by the University of Nebraska-Lincoln (heretofore referred to as UNE) was completed in the laboratory's low-speed wind tunnel located in North Platte, Nebraska, USA. The low-speed tunnel has the same dimensions and air speed capabilities as the ARS facility. The two major differences are that rather than a break in the tunnel for insertion of the Sympatec, holes are cut on each side of the tunnel, through which the system's laser and lens components are aligned. Secondly, rather than a single impaction filter system, a multi-stage impaction and carbon scrubber system is employed. Otherwise, measurement distance, nozzle traverse speed, and concurrent air velocity were identical. The Sympatec system was the same model and used the same lens and overall operational configuration as that described earlier.

2.1.4 University of Queensland, Gatton — Ground Nozzle Testing

All ground nozzle testing conducted by the University of Gatton, in Gatton, Queensland, Australia (heretofore referred to as GAT) was done using a wind tunnel with working section width of 1.2 $\times$ 1.2 m (4 $\times$ 4 ft) and length of 4 m (13 ft). The Sympatec HELOS Vario laser diffraction instrument was placed outside the working section with the laser central in the working section. The nozzle traverse system was outside the working section and nozzles were traversed vertically across the laser to provide a nine-second sample of each spray. A blower fan delivered air from the intake of the wind tunnel, which passed through laminar air straighteners before reaching the working section. Downstream of the measurements, the wind tunnel width gradually increased within a filtration section, which fed into an outlet stack with a suction fan with air velocity matched to that of the blower fan to provide constant air speed in the working section.

2.1.5 University of Queensland, Gatton — Aerial Reference Nozzle Testing

Aerial atomization droplet size tests were conducted at GAT using the same wind tunnel as the ground tests but with a narrower contraction to provide higher air speeds representing those of aircraft flight. The contraction was 0.8 $\times$ 0.8 m (2.6 $\times$ 2.6 ft).

2.2 Testing Procedures

2.2.1 ASAE S572.1 Reference Nozzle Testing

A certified set (certified by Spraying Systems based on testing to confirm nominal flow rate at nominal pressures as listed in ASAE S572.1) of reference nozzles were evaluated at all three labs using the reference pressures specified in ASAE S572.1 (450, 300, 200, 250, 200, and 150 kPa (65.3, 43.5, 29.0, 36.3, 29.0, 21.7 psi) for 11001, 11003, 11006, 8008, 6510, and 6515 nozzles, respectively). Flow rate for each nozzle was confirmed at the USDA ARS facility prior to any testing.

2.2.2 ASAE S572.1 Reference Nozzle Multi-Day Sizing Tests

In addition to examining the lab-to-lab variability in drop size for the same set of nozzles, a series of multi-day replications at the ARS and NE labs were also conducted to examine day-to-day variation. Following the protocols described earlier, the same set of certified reference nozzles were evaluated on five separate days at both labs. The same personal at each lab conducted the testing over all five tests. The day-to-day results within each lab were compared as well as pooling all five days of results for each lab and comparing the overall means between each lab.

2.2.3 Ground Nozzle Testing

A series of ground nozzles covering a number of typical types, including flat fan, air induction, and twin jets, were evaluated at all three locations across a series of nozzle orifice sizes and operating pressures. The nozzle type, manufacturer, and naming conventions are given in Table 1.

2.2.4 Aerial Reference Nozzle Testing

A set of flat fan nozzles identified by Hewitt (2008) were used for the aerial reference nozzle testing. The selected nozzles were 11001, 8003, 8005, 6515, and 4015 flat fan nozzles which corresponded to VF/F, F/M, M/C, C/VC, and VC/XC size classification thresholds, respectively. The nozzles were operated at pressures of 450, 550, 300, 400, and 280 kPa (65.0, 80.0, 43.5, 58.0, and 40.6 psi), for the 11001, 8003, 8005, 6515, and 4015 flat fan nozzles, respectively.

3. ANALYSIS

All statistical analyses were conducted using JMP ® (Version 10.0, SAS Institute, Inc., Cary, NC). All means separations were performed using Tukey's honestly significant difference (HSD) at $\alpha = 0.01$.

TABLE 1: Nozzle type, manufacturer and naming convention for ground nozzles tested

Nozzle (Naming convention)	Manufacturer	Features
Air Induction Extended Range (AIXR)	TeeJet	Venturi Type
TurboTeeJet (TT)		Dual chamber
TurboTeeJet Induction (TTI)		Dual, chamber, Venturi-Type
TurboTwinJet (TTJ60)		Dual orifice
Extended Range (XRC)		Conventional Hydraulic nozzle
Guardian (G)	Hypro	120° with 20°
Guardian Air (GA)		Venturi-Type offset
UltraLow Drift (ULD)		Venturi-Type
AirMix (AM)	GreenLeaf Technologies	Venturi-Type
TurboDrop Venturi (TDXL)		Dual cap, Venturi-Type

4. RESULTS

4.1 ASAE S572.1 Reference Nozzle Round Robin

The mean volume diameters ($D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$) and the percent spray volume diameters less than 100 µm (%Vol $<$ 100 µm) and means separations between labs are given in Table 2. Generally, the greatest variability in the reference nozzle data was seen at GAT with average standard deviation/mean values across $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$, and %Vol $<$ 100 µm of 1.5, 1.2, 0.95, and 5.9%, respectively. The ARS and UNE values were similar (0.45, 0.36, 0.53, and 2.0% for ARS and 0.77, 0.37, 0.82, and 3.1% for UNE). With one exception (GAT: 6515 %Vol $<$ 100 µm at 18%) all standard deviation/mean values were less than 5%. Given this level of precision at each lab, there were significant differences between labs, even at small numerical differences. Overall average percent differences between labs were 4.4, 4.3, 5.4, and 19.8% for $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$, and %Vol $<$ 100 µm, respectively. These differences are most likely the result of slight pres-

TABLE 2: Average volume diameters (μm) and percent spray volume diameters less than 100 μm for each of the ASAE S572.1 reference nozzles measured at each laboratory. Means within each column for each nozzle followed by the same letter are not significantly different as determined by Tukey's HSD ($\alpha = 0.01$)

Nozzle	Lab	$D_{V0.1}$		$D_{V0.5}$		$D_{V0.9}$		%Vol < 100 μm	
11001 VF/F	ARS	59.5	A	134.4	A	236.4	B	30.36	A
	GAT	61.3	A	125.5	B	205.7	C	32.24	A
	UNE	61.3	A	137.2	A	242.1	A	29.24	A
11003 F/M	ARS	110.3	B	248.1	B	409.4	B	7.88	B
	GAT	105.3	C	232.7	C	395.8	C	8.74	A
	UNE	115.2	A	255.8	A	417.4	A	7.11	C
11006 M/C	ARS	162.0	B	357.8	A	584.0	B	3.08	A
	GAT	153.2	C	335.2	B	568.3	C	3.19	A
	UNE	170.5	A	372.2	A	616.1	A	2.70	B
8008 C/VC	ARS	191.7	B	431.0	B	737.1	A	2.17	A
	GAT	198.1	A	427.6	B	703.0	A	1.71	C
	UNE	200.1	A	441.9	A	724.9	A	1.88	B
6515 VC/XC	ARS	302.5	A	658.6	A	1142.2	A	0.62	A
	GAT	306.5	A	668.3	A	1119.2	A	0.53	A
	UNE	318.1	A	661.1	A	1012.8	B	0.28	B
6510 XC/UC	ARS	226.1	B	500.9	B	819.8	C	1.45	A
	GAT	236.9	AB	520.6	A	876.2	A	1.05	B
	UNE	244.3	A	528.7	A	846.2	B	1.05	B

sure differentials due to plumbing and/or air supply capabilities to maintain pressures, as well as differences in water and air temperatures at each location. Pressure deviations were observed pressure deviations were typically no more than 13 to 20 kPa (2–3 psi) at each location as a replication was conducted, possibly due to a corresponding reduction in pressure in the air compressor tank. The increased variability at GAT may be due to the smaller air compressor volume (37.9 L versus 227.1 L (10 gal versus 60 gal) tanks at ARS and UNE). This smaller tank volume led to an increased number of compressor ON cycles changing the pressure throughout the system, requiring constant monitoring and adjustment of the pressure gauge.

4.2 ASAE S572.1 Reference Nozzle Multi-Day Sizing Tests

The multi-day volume diameters and percent spray volume diameters less the 100 and 200 μm of the certified set of reference nozzles for the ARS and NE labs are not included in this manuscript but can be obtained by contacting the corresponding author. The average standard deviation/mean ratios for each lab was 3% for the $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ values and 13 and 6% or less for the %Vol $<$ 100 μm and %Vol $<$ 200 μm, respectively, across the five days' measurements. However, given the rep to rep precision for a given nozzle at a given lab, there were significant differences between the values recorded on each of the test days. Again, these differences are likely due to differences in pressures and water and air temperature day to day. Pooling the day-to-day data at each lab and determining 99% confidence intervals showed that there were significant differences between labs, in many cases. Given the day-to-day variability at each lab, the authors propose a daily check of these reference nozzles and comparison to the developed confidence intervals prior to any particle sizing experiment. This practice will ensure proper setup and operation of equipment and allow for any discrepancies to be corrected before data collection.

4.3 Ground Nozzle Data

The volume diameters ($D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$) and the percent spray volume diameters less than 100 μm (% $<$ 100 μm) for the ground nozzles evaluated as part of this study are not included in this manuscript but can be obtained by contacting the corresponding author. Across all nozzles (all pressures and orifices) and all labs, the greatest variability (in terms of ratio of standard deviation to the mean) was seen with the G, ULD, and TT nozzles; these trends also generally hold within each lab. Overall variability (ratio of standard deviation to mean) within each lab was low. Mean ratios at the ARS lab were 0.6, 0.8, and 1.9% for $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ with maximum values of 2.3, 2.5, and 5.3%, respectively. Mean ratios at the UNE lab were 0.7, 0.7, and 1.3% for $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ with maximum values of 3.7, 4.2, and 7.1%, respectively. Mean ratios at the GAT lab were 1.4, 0.9, and 1.0% for $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ with maximum values of 4.4, 4.0, and 4.0%, respectively. This low variability led to many significant differences between labs for given nozzle and pressure combinations, even when numerical differences were small. Across all nozzle/pressure combinations, when comparing lab to lab pairs, average percent differences between mean $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values were 6.6, 5.4, and 4.8%, respectively with maximum percent differences of 14.8, 14.9, and 20.9%, respectively. The greatest average percent difference was between the GAT and UNE labs at 9.8, 7.4, and 5.2% for $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$, respectively. Average percent difference between ARS lab data and UNE and GAT ranged between 4.2 and 5.5% across all volume diameters. Generally the largest differences were seen with the G, TT, TTI, and XRC nozzles. Taking 99% confidence intervals on the percent differences across all lab/nozzle/pressure combinations returns 6.0–7.5%, 4.8–6.2%, 3.9–5.5% for $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$, respectively. The lower percent difference range for the $D_{V0.9}$ values is readily visible, as there are fewer significant differences between labs across all $D_{V0.9}$ values.

4.4 Aerial Reference Nozzle Evaluations

Means for the aerial reference nozzles evaluated at the USDA ARS, the University of Nebraska-Lincoln, and the University of Queensland, Gatton Laboratories are shown in Table 3. With a few exceptions, the aerial reference nozzle data from all labs were similar. Only the 4015 nozzle showed differences for more than one volume diameter value between all labs, for which numerical differences were 7% or less. The data generated as part of this work are very similar to the values reported by Hewitt (2008) as well as

TABLE 3: Drop size results from USDA ARS, University of Nebraska-Lincoln and the University of Queensland, Gaton laboratories in addition to values reported by Hewitt (2008) and as found for ASAE S572.1 Reference nozzles in AgDrift. Means within each column for each nozzle followed by the same letter are not significantly different as determined by Tukey's HSD ($\alpha = 0.01$). Hewitt and AgDrift data were not included in means separation

Lab	**Nozzle**	$D_{V0.1}$		$D_{V0.5}$		$D_{V0.9}$		**% < 100**		**% < 200**	
ARS	11001 VF/F	67.3	A	150.4	A	244.6	A	23.02	A	75.27	A
GAT		69.0	A	149.9	A	243.0	A	22.62	A	75.78	A
UNE		66.9	A	148.9	A	242.9	A	23.49	A	76.10	A
Hewitt		59.0		135.0		229.0					
AgDrift		63.0		138.0		237.0					
ARS	8003 F/M	128.6	B	268.7	B	460.2	C	5.44	A	28.21	A
GAT		129.4	B	267.9	B	447.2	B	5.08	A	28.17	A
UNE		120.3	A	255.9	A	425.9	A	6.04	B	31.59	B
Hewitt		118.0		256.0		422.0					
AgDrift		114.0		255.0		444.0					
ARS	8005 M/C	167.3	B	342.0	B	574.3	B	2.82	A	15.43	A
GAT		163.5	AB	333.1	A	541.2	A	2.83	A	16.34	AB
UNE		161.2	A	339.1	AB	546.1	A	3.11	B	16.59	B
Hewitt		161.0		338.0		592.0					
AgDrift		157.0		341.0		561.0					
ARS	6515 C/VC	197.8	A	441.2	A	754.5	A	2.02	B	10.25	B
GAT		212.5	B	460.0	B	788.7	B	1.56	A	8.72	A
UNE		210.2	B	466.0	B	778.4	B	1.84	B	9.00	A
Hewitt		191.0		440.0		791.0					
AgDrift		209.0		440.0		786.0					
ARS	4015 VC/XC	217.7	A	472.5	A	802.2	A	1.59	B	8.24	C
GAT		233.8	B	503.3	B	810.6	A	1.11	A	6.83	B
UNE		242.5	C	519.3	C	846.6	B	1.12	A	6.32	A
Hewitt		231.0		511.0		844.0					
AgDrift		242.0		522.0		831.0					

the values found for the ASAE S572.1 reference nozzles in AgDrift [also reported by Hewitt (2008)]. The difference seen between the current data and the Hewitt (2008) data can easily be attributed to differences in nozzle and measurement distance. Measurement distance was not reported by Hewitt (2008) and the nozzles used for this study, while matching the same flowrate and pressure specifications, were not the same set as was used in the Hewitt study.

5. CONCLUSIONS

While using the same standard methods and operational settings did not remove all of the statistical differences between each of the labs, the results were still numerically close; typically 4–8% difference between labs for the ground nozzles tested and less than 7% for the aerial nozzles with only a few statistically significant differences. Day-to-day variance within each laboratory was also found to be around 5% and can be used as a daily check by operators to ensure that all equipment is functioning properly. Results from the current study will be beneficial for developing future testing standards and operating procedure for laboratories involved in drop size measurements involving laser diffraction techniques.

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