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Effects of Air Speed and Liquid Temperature on Droplet Size

ABSTRACT: Advancements in both application hardware (e.g., nozzles and spray assist devices) and spray property modification products have led to a number of products that are specifically designed to maximize the on-target deposition and minimize off-target movement of spray droplets. Testing protocols are being developed to objectively measure spray drift reduction from a wide range of drift reduction technologies (DRTs) including spray nozzles, sprayer modifications, spray delivery assistance, spray property modifiers (adjuvants), and/or landscape modifications. Using a DRT evaluation protocol, the objectives of this work were to study the effects of different air speeds on droplet size from different spray nozzles and spray solutions and to further evaluate the effects of differences in liquid and air temperature on droplet size at the different air speeds tested. Measured spray droplet size was significantly affected by changes in airspeed with the $D_{V0.5}$ increasing by ~30–100 μm and the percent of spray volume less than 200 μm decreasing by 50 % or more as the tunnel airspeed was increased from 0.5 to 6.7 m/s (1 to 15 miles per hour), depending on the spray solution, spray nozzle, and air speed. The data also showed a lesser influence of temperature differential between the spray solution and ambient air, with the differences seen most likely resulting from changes in spray solution physical properties with the changes in liquid temperature. Most importantly, this study demonstrated that a reference nozzle evaluated under the same conditions resulted in the reduction in driftable fines while the DRT remained constant across all conditions tested.

KEYWORDS: drift, DRT, drift reduction technology, droplet sizing, climate change

Introduction

Productivity of American agriculture depends on the use and application of agrochemical products in an effective and safe manner. Advancements in both the application hardware (e.g., nozzles and spray assist devices) and spray product modifiers have led to a number of products that are specifically designed to maximize the fraction of applied spray that remains on-target and minimize the fraction that is off-target. As climate change potentially changes or affects the usage and transport of agrochemical products [1], there is a critical need to identify products that will reduce off-target movement of sprays and to quantify the reduction levels for further risk assessment. The development of a program for testing drift reduction technologies (DRT) has been a priority for the U.S. Environmental Protection Agency (EPA) since 2004 [2]. The developed program protocols are extensive as they attempt to account for a wide range of DRTs including spray nozzles, sprayer modifications, spray delivery assistance, spray property modifiers (adjuvants), and/or landscape modifications. The overall goal of this DRT program is the improved protection of human health and the environment through the use of these improved application technologies [3]. With a set of protocols, standard operating procedures, and data quality assurance steps developed and in place, several studies have been conducted to evaluate their functionality [4–7]. The goal of these studies was to ensure the testing process followed scientifically valid and repeatable methods and that data quality could be maintained [8,9].

The studies above [4–7] examined the protocols for measuring droplet size and spray flux downstream of the nozzle as a measure of drift potential. For the high speed studies [5,7], the droplet size was taken directly downstream as exiting from the nozzle. The low speed study [6] measured droplet size and spray flux that was carried downwind of a nozzle spraying toward the tunnel floor, which is different than the

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droplet size produced by the nozzle. However, the protocol does specify the need to measure the droplet size from the nozzle [10]. Additionally, a draft standard [11] is being developed that proposes to characterize the performance of spray drift reduction adjuvants through measurement of spray droplet size near the nozzle exit. Several standards and studies [11–13] note that if droplet size measurements are being made with a spatial sampling system, such as a laser diffraction device, there is a need to minimize any differential spray velocity profile of the different sized droplets within the spray to prevent bias toward the smaller, slower moving droplets. The draft standard [11] recommends conducting droplet size measurements in a 3 m/s (7 miles per hour (mph)) airstream, while the other standard [13] does not specify a velocity. The magnitude of any potential bias when testing under different airspeeds is unknown as is the optimal air speed for testing.

In addition to the potential bias from spatial sampling systems, the EPA draft protocol [11] notes a potential bias with a temperature differential between the spray solution and the ambient airstream. Recent publications [14,15] observed an influence of this temperature differential on droplet size and proposed a maximum difference in temperature between the spray liquid and surrounding air of 5 °C. Miller and Tuck [14] observed a decrease in mean droplet size from flat fan nozzles as liquid temperature increased from 15 °C to about 25 °C (assuming the air temperature remained constant but was not specified) with larger nozzles having a greater dependence than smaller ones.

With the drift reduction potential from both spray nozzles and adjuvants from ground application systems being evaluated based on the spray droplet size exiting the nozzle, there is a need to determine the potential biases that result from spatial droplet sizing under different airspeeds as well as with differences in spray solution and airstream temperature differences. Using established professional standards, such as ASTM Standard Methods for Testing Hydraulic Spray Nozzles Used in Agriculture (E361-01) [16] and ASAE Standard Spray Nozzle Classification by Droplet Spectra (S572) [17], the objectives of this work were to evaluate the effects of different wind tunnel air speeds on droplet size from different spray nozzles and spray solutions and to further evaluate the effects of differences in liquid and air temperature on droplet size at the different air speeds tested.

Materials and Methods

All tests were conducted in the U. S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Aerial Application Technology-low speed wind tunnel (LSWT) located in College Station, TX [4]. The specific operating conditions used during the testing are documented in the following sections. For these tests, the effects on spray droplet size from every combination of three spray nozzles, three spray solutions, four temperature differences between the spray solution and air, and three wind speeds were evaluated in LSWT. Since each of these combinations was replicated three times, the tests required 324 individual measurements.

Droplet Size Measurements

A Sympatec Helos laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany) was used to measure the droplet size downwind of the tested nozzles. The Helos system utilizes a 623 nm He–Ne laser and is fitted with a lens (denoted by manufacturer as R7) with a dynamic size range of 0.5–3500 μm divided across 32 sizing bins. The laser system has two components, the emitter and the receiver, which were positioned across from each other and outside of the wind tunnel. The laser was horizontally positioned so that its beam was in the center of the wind tunnel and located 0.6 m (24 in.) downwind from the nozzle.

Droplet size measurements included volume median diameter ($D_{V0.5}$), and $D_{V0.1}$ and $D_{V0.9}$. $D_{V0.5}$ is the droplet diameter (μm) where 50 % of the spray volume or mass is contained in droplets of lesser diameter. $D_{V0.1}$ and $D_{V0.9}$ values, which describe the proportion of the spray volume (10 and 90 %, respectively) contained in droplets of a specified size or less. Tests were performed within the guidelines provided by ASTM Standard E1260-05: Standard Test Method for Determining Liquid Drop Size Characteristics in a Spray Using Optical Nonimaging Light-Scattering Instruments [18]. The distance between the nozzle and laser beam was 50 cm.

TABLE 1—*Statistical analyses of the effects of differences in liquid and air temperatures on droplet size parameters by nozzle type and spray solution.*

Spray Nozzle	Spray Solution	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	$\% < 200$ μm
FF11003	NIS	ns[a]	ns	ns	ns
	SylGard 309	ns	ns	[b]	ns
	PowerMax	ns	ns	ns	ns
AI11003	NIS	ns	ns	[b]	ns
	SylGard 309	ns	[c]	[c]	ns
	PowerMax	ns	[b]	[b]	ns
CP 8008	NIS	[b]	[c]	[b]	[b]
	SylGard 309	ns	ns	ns	ns
	PowerMax	ns	ns	ns	ns

[a] ns=not significant at the $\alpha=0.05$ level.

[b] Significant at the $\alpha=0.05$ level.

[c] Highly significant at the $\alpha=0.01$ level.

Air speeds and Wind Tunnel Description

The tunnel has a cross-sectional area of 1.2 × 1.2 m (4 × 4 ft) and an overall length of 14.6 m (48 ft). Air speed can be varied from 0.2 to 5.4 m/s through the tunnel. The tunnel is outfitted with a flow straightener to produce relatively laminar flow through the tunnel. Each nozzle tested was mounted 3 m upwind of the tunnel exit on a traverse system, which allowed the nozzle to move up and down over a 1 m length. The spray plume from each nozzle was set to spray horizontally so that the entire spray plume could be traversed through the laser beam. The nozzle assembly was plumbed to a pressurized pot containing the spray solution with a pressure regulator to control spray pressure. Spray was turned on and off using a ball valve. For the PowerMax spray solutions, a power-assisted scrubber/filtration system was positioned at the end of the tunnel to capture the spray droplets exiting the wind tunnel.

Three air speeds (0.5, 3.1, and 6.7 m/s (1, 7, and 15 mph)) were use to evaluate each spray nozzle, spray solution, and temperature differential combination. The air speed was set and monitored using a hot-wire anemometer (Model 407119A, Extech Instruments, Waltham, MA). The air speed in the tunnel represents a concurrent airflow past the nozzle and through the laser beam sampling area. This concurrent flow was used to move spray droplets out of the sampling area once they have been measured.

Spray Nozzles

Two test nozzles and a reference nozzle were tested using the pesticide spray DRT protocol. The three test nozzles used in these tests were an AI-11003 VS nozzle (AI11003, Teejet Technologies, Wheaton, IL) at 300 kPa (43 psi), an 11003 Flat fan nozzle (11003, Spraying Systems Inc., Wheaton, IL) operated at 300 kPa (43 psi), and a CP11TT 8008 Flat Fan nozzle (8008, CP Products Inc., Mesa, AZ) operated at 276 kPa (40 psi). The 11003 flat fan nozzle is used to define the Fine/Medium boundary in the ASABE Standard [17] and was selected as the reference nozzle [4,5] for the DRT evaluations.

Spray Solutions

Three spray solutions were tested with each of the three nozzles and at three different air speeds. Each spray solution was mixed in an individual 19 L (5 gal) containers, then a portion of each solution was transferred to a 12 L stainless steel container that could be pressurized with compressed air. The three solutions were:

- NIS: Water with 0.25 % volume/volume (v/v) of a 90 % nonionic surfactant (NIS) (R-11, Wilbur-Ellis Co., San Antonio, TX).
- SylGard 309: Water with 0.25 % v/v of a low molecular weight nonionic silicone polyether surfactant (SylGuard 309, Wilbur-Ellis Co., San Antonio, TX).
- PowerMax: Water with 3.4 % v/v Roundup® Powermax (Monsanto Co., St. Louis, MO).

TABLE 2—*Reduction in the percent of spray contained in droplets less than 200 μm in diameter using an AI11003 nozzle as compared to the reference 11003 flat fan nozzle.*

		Spray Solution		
ΔT (°C) [a]	Air Speed (m/s)	NIS	SylGard 309	PowerMax
−5	0.5	85.6	86.4	80.3
−5	3.1	91.8	92.8	85.2
−5	6.7	92.8	94.1	89.4
0	0.5	86.6	84.7	81.0
0	3.1	90.7	92.0	85.7
0	6.7	92.9	92.6	91.3
10	0.5	85.5	81.0	76.7
10	3.1	90.2	88.6	82.3
10	6.7	92.9	90.7	89.0
20	0.5	81.7	75.5	76.4
20	3.1	89.5	89.0	80.0
20	6.7	91.6	90.4	86.9

[a] ΔT (°C) = temperature of liquid (°C) − air temperature (°C).

Temperature Differences

For this study, the temperature differential is defined as the temperature of the spray solution minus the air temperature. Therefore, −5 °C means that the spray solution was cooler than the ambient air by 5 °C. Liquid temperature was measured with a handheld thermometer (Model 39272, Extech Instruments, Waltham, MA) and air temperature was measured with a handheld weather meter (Model 4500, Kestrel Meters, Sylvan Lake, MI). Temperature differentials of −5, 0, 10, and 20 °C were generated for this study. When testing each nozzle and spray solution combination, the first step was to add small amounts of ice (<50 mL in a 20 L tank) to the spray solution in the stainless steel container. After using a paint mixer on a cordless drill to mix the spray solution, the temperature of the solution was taken and the process repeated until the liquid was 5 °C cooler than the ambient air. The droplet size measurements at the three air speeds were then conducted in less than 3 min, during which time the liquid temperature changed less than 0.5 °C. The stainless steel container was placed in a heated vat of water to heat the spray solution inside the container. The paint mixer and cordless drill were used to mix the spray solution and to evenly heat the liquid inside the container. When the liquid reached a temperature of 0, 10, and 20 °C above the ambient air temperature, the container was removed from the heated water vat and the droplet size measurements at the three air speeds were then conducted in less than 3 min.

Statistical Analyses

To test the significance of temperature differences between liquid and air temperature and the air speed effects, both temperature difference and air speed were treated as fixed effects. The Statistical Analysis System, General Linear Model (PROC GLM, SAS Institute, Cary, NC) was used to perform the analyses of variance to test the significance of each effect at the $\alpha = 0.05$ level of significance. If the probability of significance (p-value) was less than 0.05 or less than 0.01, the effect was determined to be significant or highly significant, respectively.

Results

Temperature Effects on Droplet Size Data

The droplet size measurements for all of the nozzles, air speeds, and spray solutions are provided in the Appendix in Tables 3–5. In general, the temperature differential had no significant effect on droplet size with the exception of the 8008 nozzle and NIS solution test. In this particular test, droplet size consistently decreased as the temperature differential (more specifically the liquid temperature) increased unlike the other tests conducted where there was no consistent increase or decrease in droplet size. This decrease in droplet size is consistent with changes in the physical properties of the spray solution [19]. As liquid

TABLE 3—*Spray droplet measurements under different temperature differentials and air speeds for the flat fan 11003 nozzle.*

Solution	ΔT (°C) [a]	Air Speed (m/s)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)[b]	$D_{V0.9}$ (μm)	%<200 μm[a,c]
NIS	−5	0.5	88.6 ± 2.5	172.7 ± 3.5	311.9 ± 9.4	62.3 ± 1.9
NIS	−5	3.1	100.8 ± 1.2	209.7 ± 3.9	354.3 ± 4.5	46.3 ± 1.4
NIS	−5	6.7	112.2 ± 1.7	238.9 ± 6.5	393.2 ± 16.4	36.4 ± 1.6
NIS	0	0.5	83.0 ± 0.5	166.8 ± 1.4	298.4 ± 2.6	65.6 ± 0.9
NIS	0	3.1	96.9 ± 0.7	209.2 ± 1.8	362.1 ± 3.8	46.6 ± 0.6
NIS	0	6.7	109.7 ± 1.0	235.4 ± 1.7	392.5 ± 5.8	37.5 ± 0.4
NIS	10	0.5	84.9 ± 3.1	169.8 ± 4.2	307.1 ± 8.4	63.6 ± 2.1
NIS	10	3.1	98.0 ± 2.2	207.9 ± 4.9	354.7 ± 5.8	47.0 ± 1.9
NIS	10	6.7	106.6 ± 2.3	228.7 ± 6.5	372.0 ± 15.4	39.4 ± 1.9
NIS	20	0.5	91.2 ± 4.1	183.0 ± 10.6	335.6 ± 13.7	57.0 ± 4.6
NIS	20	3.1	104.3 ± 1.5	219.4 ± 1.1	370.6 ± 7.3	43.0 ± 0.3
NIS	20	6.7	115.5 ± 1.7	243.1 ± 1.3	392.3 ± 3.7	34.9 ± 0.5
SylGard 309	−5	0.5	101.2 ± 1.2	194.2 ± 1.9	352.3 ± 1.5	52.4 ± 0.8
SylGard 309	−5	3.1	120.3 ± 0.8	231.5 ± 2.1	380.8 ± 0.9	38.1 ± 0.7
SylGard 309	−5	6.7	132.4 ± 0.9	257.7 ± 2.1	405.5 ± 7.3	29.6 ± 0.3
SylGard 309	0	0.5	100.6 ± 0.7	191.1 ± 1.3	357.1 ± 2.6	53.5 ± 0.5
SylGard 309	0	3.1	116.7 ± 5.3	233.5 ± 4.7	383.9 ± 15.3	37.9 ± 0.9
SylGard 309	0	6.7	127.5 ± 6.5	254.4 ± 4.1	406.3 ± 7.9	30.8 ± 1.1
SylGard 309	10	0.5	104.3 ± 1.6	212.7 ± 2.5	353.3 ± 4.1	45.1 ± 0.9
SylGard 309	10	3.1	130.0 ± 0.1	241.6 ± 3.1	370.5 ± 8.0	33.0 ± 1.0
SylGard 309	10	6.7	139.9 ± 2.6	251.5 ± 2.5	371.3 ± 7.7	28.4 ± 0.9
SylGard 309	20	0.5	104.9 ± 0.9	214.7 ± 1.6	356.2 ± 3.0	44.2 ± 0.6
SylGard 309	20	3.1	128.9 ± 2.8	239.5 ± 2.9	370.2 ± 8.8	34.1 ± 1.3
SylGard 309	20	6.7	140.0 ± 0.4	251.2 ± 0.4	375.7 ± 4.6	28.8 ± 0.2
PowerMax	−5	0.5	92.4 ± 1.1	176.5 ± 5.4	332.9 ± 10.3	60.2 ± 2.7
PowerMax	−5	3.1	102.2 ± 1.6	221.8 ± 0.5	404.9 ± 1.4	42.9 ± 0.2
PowerMax	−5	6.7	117.1 ± 1.6	255.9 ± 6.1	440.4 ± 6.7	33.3 ± 1.3
PowerMax	0	0.5	88.7 ± 2.1	172.6 ± 2.8	329.5 ± 6.1	62.0 ± 1.4
PowerMax	0	3.1	90.9 ± 1.1	202.8 ± 1.2	385.0 ± 6.5	49.0 ± 0.4
PowerMax	0	6.7	101.5 ± 1.0	226.7 ± 3.6	402.3 ± 13.3	41.3 ± 0.9
PowerMax	10	0.5	89.1 ± 1.9	171.8 ± 6.7	324.0 ± 23.3	62.4 ± 3.8
PowerMax	10	3.1	97.3 ± 2.0	205.1 ± 6.0	363.2 ± 10.1	48.2 ± 2.1
PowerMax	10	6.7	108.0 ± 1.6	234.2 ± 0.7	401.1 ± 2.4	38.8 ± 0.2
PowerMax	20	0.5	87.7 ± 1.6	170.3 ± 4.7	317.7 ± 8.1	63.3 ± 2.3
PowerMax	20	3.1	95.0 ± 1.5	208.9 ± 4.4	387.4 ± 7.0	47.0 ± 1.4
PowerMax	20	6.7	101.8 ± 0.9	225.6 ± 0.4	393.6 ± 4.5	41.6 ± 0.2

[a] ΔT (°C) = temperature of liquid (°C) − air temperature (°C).

[b] $D_{V0.5}$ = volume median diameter.

[c] % < 200 μm = percentage of spray volume comprised of droplets less than 200 μm in diameter.

temperature increases, the dynamic surface tension and viscosity decrease, which results in smaller droplets. This is a result of less physical forces being present in the liquid to hold droplets together.

Air speed Effects

The effect of LSWT air speed on droplet sizes was highly significant ($p < 0.01$) for all combinations of spray nozzle and spray solution (Table 1). As can be seen by looking at the data in Tables 3–5, for every test conducted, the overall droplet size increased as the air speed in the tunnel was increased from 0.5 to 6.7 m/s. The increase in $D_{V0.5}$ was around 100 μm over the range of air speeds tested while the percent of spray contained in less than 200 μm droplets decreased by 50 % or more from the lowest to the highest air speed.

This is a result of the residence time that smaller droplets spend in the laser beam and is referred to as spatial sampling bias [20]. When there are a number of different size droplets in the laser beam, an aggregate sample is compiled by the measurement system. Smaller droplets (i.e., smaller mass) decelerate more than larger droplets once they leave the nozzle. If the air speed in the wind tunnel is low, these small

TABLE 4—*Spray droplet measurements under different temperature differentials and air speeds for the AI11003 nozzle.*

Solution	ΔT (°C) [a]	Air Speed (m/sec)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)[b]	$D_{V0.9}$ (μm)	%<200 μm[a,c]
NIS	−5	0.5	209.0 ± 1.4	521.2 ± 0.2	879.6 ± 15.0	9.0 ± 0.2
NIS	−5	3.1	289.0 ± 5.7	589.5 ± 8.5	891.8 ± 11.7	3.8 ± 0.2
NIS	−5	6.7	317.6 ± 1.7	618.7 ± 4.5	912.6 ± 8.6	2.6 ± 0.0
NIS	0	0.5	210.5 ± 5.0	508.4 ± 10.5	840.6 ± 20.3	8.8 ± 0.5
NIS	0	3.1	274.0 ± 2.3	568.0 ± 5.0	854.4 ± 8.4	4.3 ± 0.1
NIS	0	6.7	315.4 ± 4.8	619.3 ± 8.5	975.7 ± 7.8	2.7 ± 0.2
NIS	10	0.5	206.7 ± 1.6	493.2 ± 1.1	801.3 ± 3.9	9.2 ± 0.2
NIS	10	3.1	269.2 ± 3.3	561.0 ± 6.5	854.4 ± 5.6	4.6 ± 0.2
NIS	10	6.7	311.2 ± 0.7	603.6 ± 1.6	906.2 ± 1.5	2.8 ± 0.0
NIS	20	0.5	197.4 ± 3.6	472.1 ± 4.0	792.3 ± 8.4	10.4 ± 0.5
NIS	20	3.1	269.8 ± 2.2	555.4 ± 7.4	841.4 ± 17.7	4.5 ± 0.1
NIS	20	6.7	304.6 ± 1.1	587.5 ± 4.7	864.5 ± 31.9	2.9 ± 0.1
SylGard 309	−5	0.5	229.1 ± 3.1	536.7 ± 4.1	843.0 ± 9.8	7.1 ± 0.3
SylGard 309	−5	3.1	310.9 ± 2.1	597.5 ± 2.9	862.7 ± 6.8	2.7 ± 0.1
SylGard 309	−5	6.7	347.6 ± 3.5	638.0 ± 3.5	972.7 ± 11.6	1.7 ± 0.1
SylGard 309	0	0.5	217.4 ± 9.5	512.6 ± 8.5	819.6 ± 18.6	8.2 ± 1.0
SylGard 309	0	3.1	301.0 ± 1.1	569.2 ± 2.2	830.0 ± 0.7	3.0 ± 0.1
SylGard 309	0	6.7	321.3 ± 4.7	590.8 ± 6.8	842.2 ± 2.6	2.3 ± 0.1
SylGard 309	10	0.5	212.6 ± 6.3	473.9 ± 3.5	747.3 ± 22.7	8.6 ± 0.7
SylGard 309	10	3.1	279.4 ± 0.6	533.4 ± 4.2	817.5 ± 21.2	3.8 ± 0.1
SylGard 309	10	6.7	305.9 ± 2.1	559.9 ± 1.2	848.9 ± 5.2	2.6 ± 0.1
SylGard 309	20	0.5	193.3 ± 10.5	455.5 ± 6.7	711.5 ± 15.7	10.8 ± 1.2
SylGard 309	20	3.1	278.1 ± 1.9	518.5 ± 4.9	757.5 ± 15.5	3.8 ± 0.1
SylGard 309	20	6.7	302.9 ± 2.3	540.7 ± 1.2	784.2 ± 2.0	2.8 ± 0.1
PowerMax	−5	0.5	187.5 ± 3.8	454.6 ± 8.4	793.7 ± 12.0	11.8 ± 0.6
PowerMax	−5	3.1	241.7 ± 1.9	535.6 ± 3.1	837.4 ± 3.2	6.3 ± 0.1
PowerMax	−5	6.7	287.8 ± 2.9	588.1 ± 5.2	906.5 ± 7.5	3.5 ± 0.1
PowerMax	0	0.5	187.8 ± 4.2	452.5 ± 10.5	797.9 ± 13.0	11.8 ± 0.7
PowerMax	0	3.1	232.7 ± 8.2	525.3 ± 4.0	842.4 ± 4.5	7.0 ± 0.8
PowerMax	0	6.7	288.3 ± 9.6	579.7 ± 6.2	869.1 ± 5.9	3.6 ± 0.5
PowerMax	10	0.5	172.7 ± 1.1	414.0 ± 0.4	759.2 ± 3.3	14.5 ± 0.2
PowerMax	10	3.1	214.9 ± 8.5	496.4 ± 6.0	806.1 ± 2.1	8.5 ± 0.9
PowerMax	10	6.7	274.7 ± 4.4	570.0 ± 6.4	918.9 ± 5.1	4.3 ± 0.2
PowerMax	20	0.5	169.9 ± 5.2	405.1 ± 7.8	730.1 ± 9.8	14.9 ± 1.0
PowerMax	20	3.1	206.1 ± 6.8	478.7 ± 5.3	794.3 ± 5.8	9.4 ± 0.7
PowerMax	20	6.7	254.0 ± 10.8	529.8 ± 10.5	834.0 ± 3.5	5.4 ± 0.7

[a] ΔT (°C)=temperature of liquid (°C)−air temperature (°C).

[b] $D_{V0.5}$=volume median diameter.

[c] %<200 μm=percentage of spray volume comprised of droplets less than 200 μm in diameter.

droplets reach the air speed in the tunnel rapidly (within a short distance; it might not be true for within a short time), causing them to remain in the laser beam sampling window longer than the larger droplets which will tend to pass through the measurement plane at velocities greater than the surrounding airstream. This phenomenon causes the small droplets to be oversampled relative to the larger droplets; thereby, biasing the droplet size measurements [21]. This bias toward small droplets can also occur in wind tunnels or spray chamber that allow small droplets to recirculate through the laser measurement window.

Relative Differences in Spray Droplet Measurements

To develop the testing protocols for the measurement of drift reducing technologies (DRT), it is essential to have a protocol robust enough for different testing facilities or laboratories to reach the same conclusions regarding the relative effectiveness of a proposed DRT in reducing spray drift. The percent of spray contained in droplets less than 200 μm in diameter (%<200 μm) represents the portion of spray with the highest drift potential. Therefore, the reduction in %<200 μm for the FF11003 nozzle, which has been selected as the reference system for evaluating DRTs [4,5], can be used to determine the DRT potential for

TABLE 5—*Spray droplet measurements under different temperature differentials and air speeds for the 8008 nozzle.*

Solution	ΔT (°C) [a]	Air Speed (m/s)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)[b]	$D_{V0.9}$ (μm)	%<200 μm[a,c]
NIS	−5	0.5	132.8 ± 2.9	329.5 ± 3.3	603.1 ± 19.6	24.0 ± 0.4
NIS	−5	3.1	158.3 ± 1.1	376.8 ± 2.5	661.9 ± 8.4	16.5 ± 0.3
NIS	−5	6.7	184.8 ± 0.8	408.5 ± 1.5	695.0 ± 5.6	12.1 ± 0.1
NIS	0	0.5	126.4 ± 4.4	316.7 ± 1.6	598.7 ± 10.5	26.2 ± 0.5
NIS	0	3.1	149.5 ± 0.5	364.2 ± 0.2	661.2 ± 2.4	18.4 ± 0.1
NIS	0	6.7	177.7 ± 1.3	399.2 ± 0.4	690.0 ± 4.7	13.2 ± 0.2
NIS	10	0.5	126.0 ± 0.4	305.2 ± 2.2	572.3 ± 8.7	27.2 ± 0.3
NIS	10	3.1	143.3 ± 1.3	342.9 ± 1.4	587.3 ± 2.0	20.2 ± 0.3
NIS	10	6.7	168.1 ± 2.5	375.9 ± 3.7	627.0 ± 12.1	14.9 ± 0.5
NIS	20	0.5	120.0 ± 1.9	287.5 ± 7.7	537.9 ± 20.7	30.1 ± 1.3
NIS	20	3.1	136.0 ± 1.1	331.9 ± 2.9	584.5 ± 4.0	21.9 ± 0.4
NIS	20	6.7	159.8 ± 1.7	361.3 ± 3.7	606.6 ± 11.4	16.5 ± 0.5
SylGard 309	−5	0.5	179.7 ± 4.4	395.7 ± 0.9	649.6 ± 15.5	13.1 ± 0.7
SylGard 309	−5	3.1	220.0 ± 0.2	430.3 ± 1.1	671.0 ± 2.2	7.7 ± 0.1
SylGard 309	−5	6.7	241.2 ± 2.4	453.6 ± 4.0	683.7 ± 7.0	5.7 ± 0.2
SylGard 309	0	0.5	126.6 ± 2.2	308.3 ± 4.7	580.5 ± 10.2	26.7 ± 0.9
SylGard 309	0	3.1	154.3 ± 6.3	359.1 ± 2.4	607.8 ± 5.9	17.5 ± 0.8
SylGard 309	0	6.7	183.6 ± 0.4	393.4 ± 1.5	656.9 ± 3.4	12.4 ± 0.1
SylGard 309	10	0.5	174.5 ± 1.4	386.3 ± 3.5	635.5 ± 10.9	14.0 ± 0.3
SylGard 309	10	3.1	221.2 ± 0.8	432.5 ± 0.4	692.5 ± 1.9	7.5 ± 0.1
SylGard 309	10	6.7	237.7 ± 0.7	448.6 ± 1.1	701.3 ± 4.1	5.9 ± 0.1
SylGard 309	20	0.5	179.8 ± 0.6	380.3 ± 2.1	583.2 ± 4.9	13.1 ± 0.1
SylGard 309	20	3.1	215.9 ± 2.0	421.7 ± 2.4	661.2 ± 5.6	8.2 ± 0.3
SylGard 309	20	6.7	235.2 ± 1.5	443.5 ± 1.8	674.1 ± 5.4	6.2 ± 0.1
PowerMax	−5	0.5	121.0 ± 1.6	280.5 ± 7.5	558.1 ± 17.2	31.1 ± 1.1
PowerMax	−5	3.1	132.8 ± 1.0	311.5 ± 2.8	554.8 ± 9.8	24.4 ± 0.4
PowerMax	−5	6.7	157.7 ± 2.0	355.5 ± 2.9	660.0 ± 14.5	17.4 ± 0.5
PowerMax	0	0.5	114.0 ± 1.7	263.6 ± 4.0	533.1 ± 7.4	34.5 ± 0.9
PowerMax	0	3.1	125.1 ± 0.4	303.0 ± 1.2	562.0 ± 6.1	26.5 ± 0.2
PowerMax	0	6.7	147.7 ± 0.7	345.1 ± 1.5	669.3 ± 18.7	19.5 ± 0.1
PowerMax	10	0.5	117.1 ± 1.7	268.4 ± 3.1	535.9 ± 10.8	33.2 ± 0.7
PowerMax	10	3.1	130.1 ± 1.2	307.1 ± 4.4	564.9 ± 13.2	25.3 ± 0.5
PowerMax	10	6.7	152.5 ± 1.9	347.7 ± 6.8	656.1 ± 48.5	18.7 ± 0.6
PowerMax	20	0.5	114.2 ± 0.4	260.7 ± 1.8	516.8 ± 17.7	34.8 ± 0.6
PowerMax	20	3.1	127.6 ± 0.3	304.2 ± 0.4	571.9 ± 0.9	26.2 ± 0.1
PowerMax	20	6.7	150.8 ± 4.9	343.7 ± 6.6	633.2 ± 18.7	19.1 ± 1.1

[a] ΔT (°C)=temperature of liquid (°C)−air temperature (°C).

[b] $D_{V0.5}$=volume median diameter.

[c] %<200 μm=percentage of spray volume comprised of droplets less than 200 μm in diameter.

the other nozzles tested (Table 2). Under all air speed and temperature differential conditions tested, the AI11003 nozzle reduced the driftable portion of spray by >75 %. These results support previous studies [5–7] conclusions that when conducting DRT tests, the use of a reference nozzle or system is required and must be evaluated under the same conditions as the DRT.

When comparing the differences in the percent reduction of spray less than 200 μm for the different spray solution, it is apparent that these differences are dependent upon the spray solutions tested. In other words, the level of reduction of %<200 μm for the AI11003 as compared to the 11003 reference nozzle, differs with the spray solution tested. Looking at the solutions tested in this study, the percent reduction in fines measured using the PowerMax solution are less than those seen with the two adjuvant solutions. This demonstrates the importance of the active ingredient effects, at least for the solutions and conditions tested here.

Conclusions

Measured spray droplet size was significantly affected by changes in airspeed with the $D_{V0.5}$ increasing by ∼30−100 um and the percent of spray volume less than 200 μm decreasing by 50 % or more as the tunnel airspeed was increased from 0.5 to 6.7 m/s (1 to 15 mph), depending on the spray solution, spray nozzle, and airspeed. This was an effect of the spatial sampling bias seen with laser diffraction instruments, which are sensitive to velocity differences between different size spray droplets. The higher air speeds reduced the velocity profile gradient between the different droplet sizes resulting in the larger and smaller sized spray droplets being sampled at the same rate increasing the measured droplet sizes. The data also showed a lesser influence of temperature differential between the spray solution and ambient air, with the differences seen most likely resulting from changes in spray solution physical properties with the changes in liquid temperature. Most importantly, this study demonstrated that by including a reference nozzle evaluated under the same conditions as the proposed DRT, the percent reduction in driftable fines remained relatively constant across all conditions tested. The use of a reference nozzle or system is critical to the success of any testing program that will be conducted at multiple test locations and under different operational conditions.

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