Air and Spray Mixture Temperature Effects on Atomization of Agricultural Sprays

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ABSTRACT

Spray drift associated with agrochemical operations is highly dependent upon the physical properties of the spray solution with respect to how they influence atomization. This study examined two spray solutions across a wide range of solution temperatures for two nozzles spraying into two high speed airstreams. The dynamic surface tension and viscosity of the spray solutions were also measured across the range of temperatures. Generally as the solution temperature increased, the dynamic surface tension and viscosity both decreased. This decrease in physical properties was directly related to the decrease in spray droplet size for all nozzles and airspeeds tested. Monitoring of spray solution temperature throughout the spray system of a typical agricultural aircraft demonstrated that while changes in the spray solutions temperature do occur, the range is much less than the ranges across which this atomization study covered. During a typical aerial application scenario, the temperature of a spray solution and the associated physical properties and atomization characteristics would not be expected to see significant variation.

Keywords: Aerial application, spray atomization, spray mixture temperature, climate change.

1. INTRODUCTION

Spray drift associated with agricultural spray operations is a major concern both to the public and to the agricultural industry. The off-target movement of spray represents a reduction in dosage on the intended target and has the potential to cause damage to other crops and result in adverse environmental and human health effects. Alistair et al. (2009) reasoned that the potential increases in pest pressure due to climate change will increase the usage of crop protection products, which will demand a greater understanding of the driving forces behind spray transport. The droplet size associated with applied spray has been identified as one of these driving forces (Bird, 1995; Hewitt et al., 2002). The atomization of agricultural sprays is a result of a number of factors including the physical properties of the spray solution (Hewitt et al., 2002; Hoffmann et al., 1998; Hewitt et al., 1993). Downer et al. (1998) described the effect of temperature on the atomization of a range of agricultural spray liquids, from approx. 3 °C to 40 °C, for water, a nonionic surfactant, two polymeric adjuvants, two blank formulations of an insecticide [an emulsifiable concentrate (EC) and a wettable powder (WP)], and two organo-silicone surfactants. Generally, Downer et al. (1998) found that the potential for drift (% volume < 150 µm) was increased to varying degrees with increasing carrier liquid temperature, but not for all the spray liquids tested, with the wettable powder a notable exception. The research reported reinforces previous work (Rizk and Lefebvre, 1989) suggesting that the relationship between physicochemical properties of liquids and the atomization characteristics of those spray liquids is far from simple and cannot be predicted from simple measurements of surface tension or viscosity based on our current experimentation. The data also showed that the particulate (WP) formulation was the most stable when atomized (i.e., least prone to change), and that the effect on atomization of the often multiple components of agricultural spray formulations still represents significant opportunities for improved understanding.

Nicholas (2000) discussed a broad range of factors that affect treatment efficacy and environmental impact from aerial insecticide application to forests. There are some key differences between insecticide applications in forestry and agriculture as he pointed out in the paper. Under the context of forest insecticide applications, he conceptually stated that the tank mix viscosity, including low temperature viscosity, was an important characteristic due to its effect on liquid flow rate. A high viscosity cut down the flow rate and reduced the volume application rate, possibly resulting in sub-optimum droplet coverage. Miller and Tuck (2005) stated that temperature of both spray liquid and the surrounding air have been shown to influence droplet size distribution measurements. Therefore, they proposed that measurement protocols specify a maximum difference in temperature between the spray liquid and surrounding air of 5°C. The statement is based on a study (Parkin, 2003) to quantify variability in the measurement of nozzle performance in laboratory conditions, which identified that temperature effect could be significant.. Results from the study were verified by making an additional set of measurements (Tuck and Miller, 2005), which concluded that temperature effects were influencing spray formation and not just the measuring system being used. The influence of solution and air temperature on spray atomization under aerial application conditions have not been reported on in the literature.

2. OBJECTIVES

The objectives of this study were to determine the changes in atomization of several spray solutions at various liquid temperatures and physical property states at aerial application airspeeds. A secondary objective was to monitor and evaluate the range of spray solution temperatures actually present in an aircraft spray boom during a typical application scenario.

3. MATERIALS AND METHODS

3.1 High Speed Wind Tunnel Droplet Size Measurements

All droplet size evaluations were conducted at the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Areawide Pest Management Research Unit (APMRU) high speed wind tunnel facility as previously described by Kirk (2007). Two spray solutions (water plus 0.25% (v/v) Triton X-100 (Rhom and Haas) and water plus 0.25% (v/v) of a 90% non-ionic surfactant (NIS) at five temperatures (20, 25, 30, 35, and 40 °C) were evaluated for droplet size. Each spray solution at each temperature was sprayed through two nozzles; an 8008 flat fan nozzle (Spraying Systems, Inc., Wheaton, IL) and a CP-03 (CP Products Co., Inc., Tempe, AZ) with the 3.2 mm orifice and 30° deflector. Both nozzles were operated at a spray pressure of 241 kPa. The 8008 flat fan nozzle was oriented such that the nozzle pointed straight back relative to the airstream while the CP-03 nozzle also pointed straight back however, the CP-03 nozzle has a 55 degrees deflector that directs the spray down relative to the airstream, which increases the airshear on the spray. The 8008 flat fan nozzle was evaluated for each spray solution and temperature at airspeeds of 177 and 225 km/h and the CP-03 nozzle was evaluated only for the Triton solution at each temperature at an airspeed of 177 km/h.

Spray solution temperatures were established by recirculation through a centrifugal pump attached to a spray reservoir. Solution temperature was monitored using a thermocouple (T-type – Copper-Constantan) attached to a datalogger (Model CR21X, Campbell Scientific, Inc., Logan, UT). Temperature data was sampled every ten seconds and reported every 30 seconds (average of three readings). When established spray solution temperatures were reached, droplet sizing measurements were taken.

A PMS laser spectrometer system (OAP-2D-GAI probe and PC-compatible OAP-1000 data acquisition system, Particle Measurement Systems, Inc., Boulder, CO) was used to collect atomization data. Sampling methods were conducted following procedures established by Kirk (2007), Three replicated measures were taken at each spray solution/solution temperature/nozzle/airspeed combination. For each set of treatments, the volume median diameter, (VMD or $D_{V0.5}$), and the $D_{V0.1}$ and $D_{V0.9}$ were reported (ASTM E1620, 2004). $D_{V0.5}$ is the droplet diameter (µm) where 50% of the spray volume is contained in droplets of lesser diameter. $D_{V0.1}$ and $D_{V0.9}$ values also were calculated, which describe the proportion of the spray volume (10% and 90%, respectively) contained in droplets of the specified size or less.

3.2 Spray Solution Physical Property Measurements

The dynamic surface tension and viscosity of each solution at each temperature were measured. Dynamic surface tension was measured with a SensaDyne Surface Tensiometer 6000 (Chem-Dyne Research Corp., Mesa, AZ) using the maximum bubble pressure method. The gas flow rate settings were varied until surface age values were found less than and greater than 0.02 s. Then, a table of percent flow rate settings was built in 5 % increments to include the previous settings. This table was calibrated using 200 proof ethanol and pure water. The probes were lowered into the sample and the dynamic surface tension, bubble rate, bubble age, and temperature were measured at each setting in the table. The dynamic surface tension at 20 ms was linearly interpolated from the results. The tests were replicated three times. Viscosity was measured with a Brookfield Synchro-Lectric Viscometer (Model LVT, Brookfield Engineering, Middleboro, MA) using a UL adapter 0.1–100 cps range. The spindle was inserted into the sample. The motor was started and run until the dial reading stabilized and the reading was recorded. This was replicated three times.

3.3 Spray Solution Temperature Monitoring of Aircraft Boom in Operation

The temperature of the spray solution during a typical application scenario was monitored at multiple locations in the spray system. A turbine powered AirTractor AT-402B (Air Tractor, Inc., Olney, TX) was used for the study and was outfitted with 24 CP-03 nozzles (operated at the same parameters as described in Section 3.1 other than the nozzles were oriented straight back). The aircraft spray system was outfitted with eight T-type thermocouples, positioned in various locations), that were attached to a data logger (similar to setup described in Section 3.1). The thermocouple locations were established to monitor the spray solution temperature (1) inside the hopper, (2) directly out of the hopper 0.38 m before the pump inlet, (3) 0.05 m after the pump outlet, (4) 0.3 m prior to the tee going to the left and right booms, (5) 0.36 m and (6) 4.9 m from the tee down the left boom, and (7) 0.9 m and (8) 5 m from the tee down the right boom. The temperatures were recorded every second during a flight trial. The flight mission consisted of a 10 minute ferry, with the recirculation pump in operation and then 15 five second spray intervals with approximately 20 seconds of no-spray between spray passes. The hopper was filled with 379 L of water such that with each spray interval the volume would decrease which resulted in less material to re-circulate increasing any heating effects of the solution.

4. RESULTS AND DISCUSSIONS

4.1 Spray Solution Physical Properties

The dynamic surface tension and the viscosity of both spray solutions decreased with increasing temperature (Fig. 1 and 2). The surface tension of the water with 0.25% Triton X-100 solution decreased from 42 to 34 mN/m @ 20 ms as solution temperature increased from 10 °C to over 40 °C (Fig. 1). Under this same solution temperature increase, the viscosity decreased from 1.2 to less than 0.8 cP (Fig. 1). The water with 0.25% NIS (90%) solution had similar results with the surface tension decreasing from 50 to less than 42 mN/m and the viscosity decreasing from less than 1 to approximately 0.8 cP, under the same temperature increases (Fig. 2).

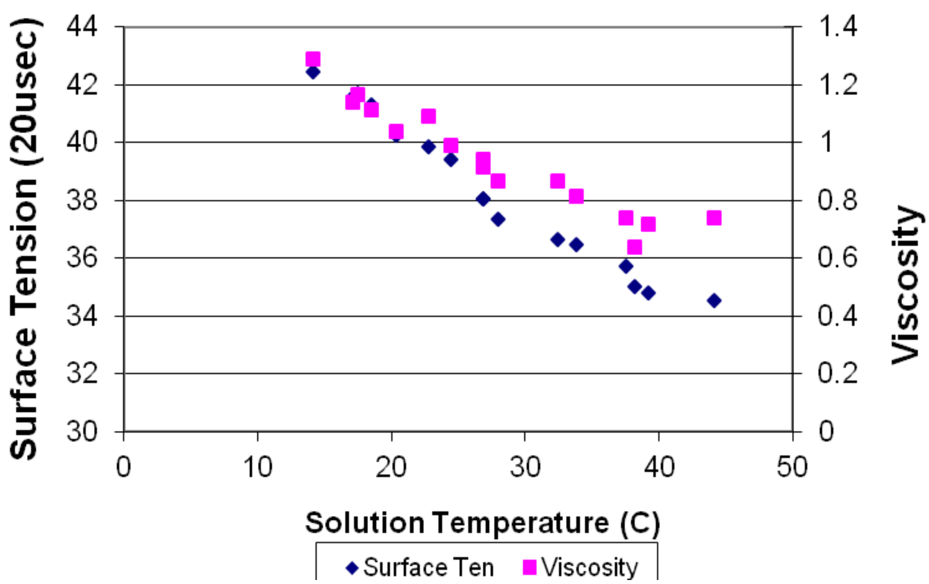

Figure 1. Physical properties of water + 0.25% (v/v) Triton X-100 with increasing solution temperature.

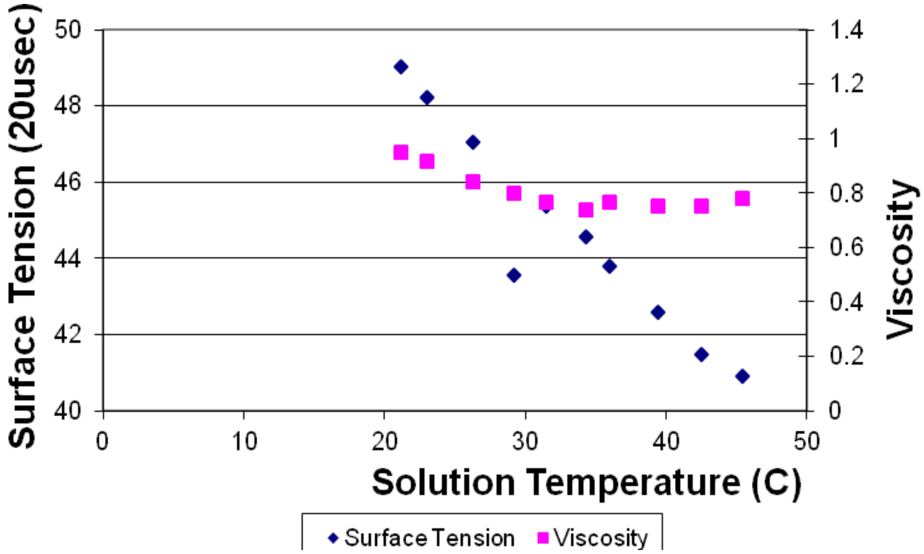

Figure 2. Physical properties of water + 0.25% (v/v) NIS (90%) with increasing solution temperature.

4.2 Physical Property Effects of Atomization

Increases in solution temperature, which resulted in decreased solution surface tensions and viscosity, resulted in decreases in VMDs for all spray solution/nozzle/airspeed combinations (Fig. 3). While there were some differences in the curves for spray VMD versus the air and spray temperature differential (Fig. 4), the trends are the same. The air temperature was not a factor in changing the spray solution physical properties and thus provided an insignificant effect on spray atomization.

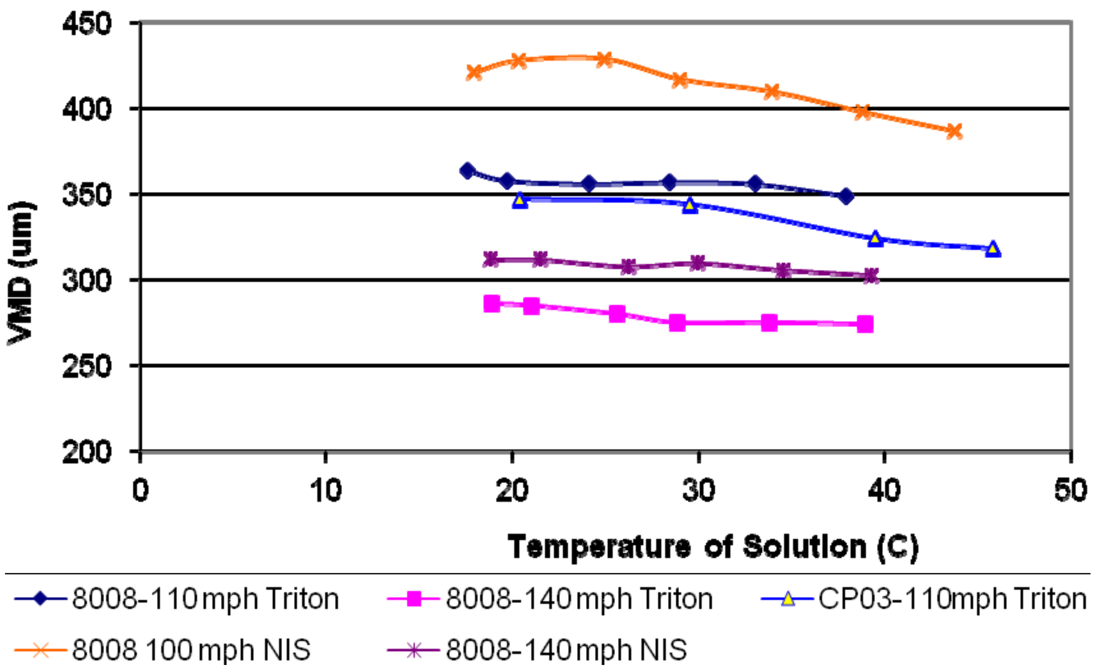

Figure 3. Solution temperature and surface tension effects on atomization

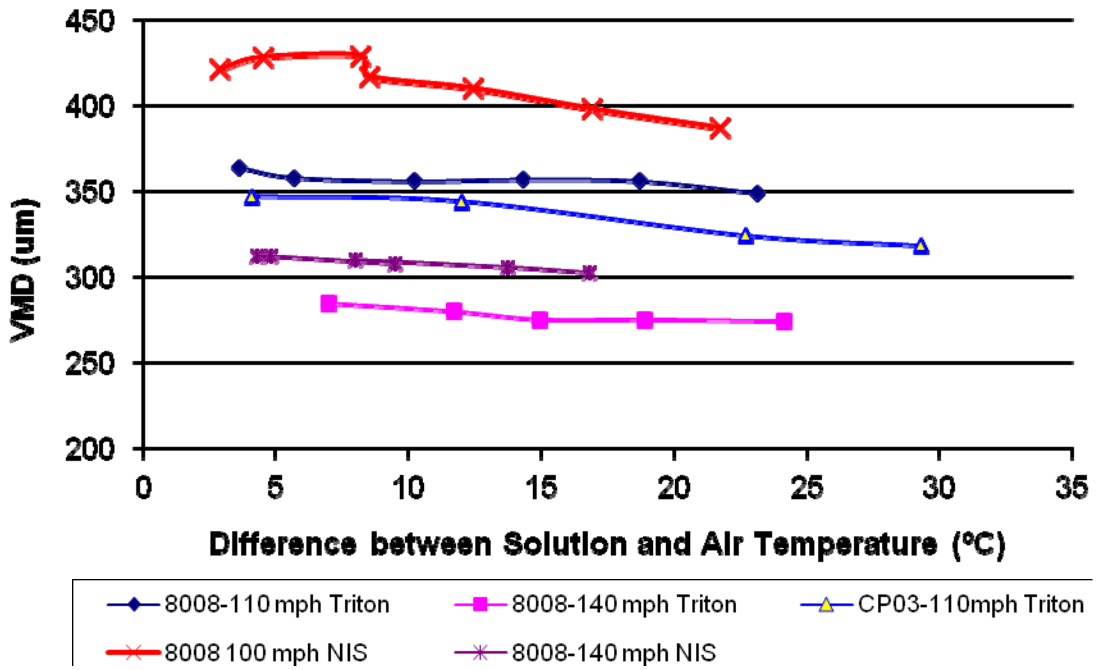

Figure 4. Differential air and spray solution temperature effects on atomization.

While the change in the solutions' surface tension resulted in the spray VMDs changing by as much as 42 µm (8008 flat fan nozzle spraying water plus 0.25% NIS into 177 km/h airstream), the changes in the $D_{V0.1}$ (more drift prone portion of the spray) were much less with a maximum change of 21 µm (same nozzle, solution and airspeed). The changes in the $D_{V0.9}$ were much greater than both the VMD and $D_{V0.1}$ with a maximum change of 64 µm (again for the same nozzle, solution and airspeed). For all droplet size parameters, changes in the physical properties had less impact at the higher airspeed as a result of the increased influence of airshear on spray atomization.

4.3 Spray Solution Temperature Monitoring on During Operation of Spray Aircraft

Monitoring the spray solution temperature onboard the aircraft across the spray system showed that the spray solution temperature in the hopper (and in the plumbing surrounding the pump) increased as a result of recirculation through the pump, though the increase was minimal (approximately 1.5 °C). . With the initiation of the first spray pass, the spray solution temperature within the boom at the tee then remained approximately equal to that of the solution in the hopper. Once spraying ceased, the spray solution temperature at the nozzles immediately started to return to ambient temperature. Each time that spraying was initiated, the spray solution temperature at the nozzle immediately approached that in the spray boom. Additional trials following these same protocols showed that in cases where the air temperature was greater than the spray solution, the temperature at the nozzle increased to that of the air temperature when spraying ceased. This effect was seen at the spray nozzles at the far ends of the left and right booms, which started out with temperatures much closer to the air temperature than those at the center nozzles. Overall, it was observed that the maximum increase in spray solution was 2.5

°C, across which changes in spray solution physical properties and atomization characteristic were minimal.

5. DISCUSSION AND CONCLUSIONS

Miller and Tuck (2005) “proposed that measurement protocols specify a maximum difference in temperature between the spray liquid and surrounding air of 5°C”. This conclusion was based on a data set taken across two different air temperatures using water as the spray solution. They conclude that “stable {droplet size} measurements will be made when the temperature difference (liquid minus air) is greater than -5°C”. This data corresponded to liquid temperatures of 3 and13°C at air temperatures of 18 and 28°C, respectively. When the difference between the liquid and air temperature increased from -5°C to 20°C, Miller and Tuck (2005) measured small decreases in droplet size for both air temperatures tested, which is consistent with the data reported in this manuscript. Miller and Tuck’s (2005) data, along with the data presented herein demonstrates that differences between air and liquid temperature has negligible effects on spray atomization and that it is the effects of liquid temperature on the physical properties of the spray that can affect spray atomization (Rizk and Lefebvre, 1989**)**.

Given the critical role that droplet size plays in the transport and fate of aerially applied agricultural sprays, the need to understand how changes in a spray solution’s physical properties effects atomization is essential. Monitoring the temperature of the spray solution onboard an agricultural aircraft during a simulated spray situation demonstrated small changes in the solution temperature (less than 3 °C) as a result of continued recirculation through the pump. The results of this study demonstrated that atomization characteristics of a specific spray solution were directly dependent upon the physical properties which were in turn highly related to liquid temperature. While spray droplet size did change with the physical properties, it was minimal across the large range of solution temperatures evaluated. During a typical aerial application scenario, the temperature of a spray solution and the associated physical properties and atomization characteristics would not be expected to see significant variation.

6. DISCLAIMER

Mention of a commercial or proprietary product does not constitute an endorsement for its use by the U. S. Department of Agriculture.

7. REFERENCES

Alistair, B.A., A. H. Boxall, S. Beulke, T. Boucard, L. Burgin, P. D. Falloon, P. M. Haygarth, T. Hutchinson, R.S. Kovats, G. Leonardi, L.S. Levy, G. Nichols, S.A. Parsons, L. Potts, D. Stone, E. Topp, D.B. Turley, K. Walsh, E.M.H. Wellington,R.J. Williams. 2009. Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture.

Environmental Health Perspectives 117(4): 508-514.

Annual Book of ASTM Standards. 2004. E 1620: Standard Terminology Relating to Liquid Particles and Atomization. West Conshohocken, PA.: ASTM International. .

Bird, S. L. 1995. A compilation of aerial spray drift field study data for low-flight agricultural application of pesticides. In Environmental Fate Studies: State of the Art, 195-207. M. L. Leng, E. M. K Loevey, and P. L. Zubkoff. eds. Chelsea, Mich.: Lewis Publishers.

Downer, R. A., F. R. Hall, R. S. Thompson, and A. C. Chapple. 1998. Temperature effects on atomization by flat-fan nozzles: implications for drift management and evidence for surfactant concentration gradients. *J. International Institutes for Liquid Atomization and Spray Systems.* 8: 241-254.

Hewitt, H. J., E.W. Huddleston, R. Sanderson, and J.B. Ross. 1993. Effect of adjuvants and formulations on aerial spray drift potential. *Pest Sci* 37(2): 209-211.

Hewitt, A. J., D. R. Johnson, J. D. Fish, C. G. Hemansky, and D. L. Valcore. 2002. Development of the spray drift task force database for aerial applications. *Environ Tox Chem* 21(3):648-658.

Hoffmann, W. C., J. R. Lingren, J. R. Coppedge, and I. W. Kirk. 1998. Application parameter effects on efficacy of a semiochemical-based insecticide. *Appl Engr Agric* 14(5): 459-463.

Kirk, I.W. 2007. Measurement and prediction of atomization parameters from fixed-wing aircraft spray nozzles. *Trans ASABE* 50(3): 693-703.

Miller, P. C. H. and C. R. Tuck. 2005. Factors influencing the performance of spray delivery systems: a review of recent developments. *J ASTM Int*, 2(6): 1-13.

Nicholas J. P. 2000. Factors influencing aerial insecticide application to forests. *Int Pest Manag Reviews*, 5: 1–10.

Parkin, C. S. 2003. Factors influencing the variability of spray nozzle performance. Report to Defra. Ref. PA 1731.

Rizk, N. K., and A. H. Lefebvre. 1980. Influence of liquid film thickness on airblast atomization. *Trans ASME J Eng Power*, 102:706-710.

Tuck, C. R. and P. C. H. Miller. 2005. The measurement of droplet size distributions in the sprays from different agricultural nozzle design. *Crop Prot* 16(7):619-628.