Understanding the Use of Atomizing Gas to Shape and Adjust Velocity of Ultrasonic Atomizer Spray

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Abstract

Ultrasonic Atomizer Technology has been on the market for over 30 years; still this technology has a number of limitations as it relates to the softness and / or the shaping of the spray. Typically this type of atomizer produces a cone type spray consisting of very fine droplets. In many cases the spray is smoke like with droplets on the order of 25 microns or less ($D_{V0.5}$). In general it is difficult to make the spray useful in industrial applications in the state that the spray leaves the atomizer. This is due, in part, to the fact that the spray has droplets with very little mass. Because the droplets are produced by ultrasonic vibration and not by pressure or an atomizing gas the droplets tend to drift with local air current which results in a spray pattern that deteriorates shortly after exiting the atomizing surface.

Spraying Systems Co. has recently developed a new patented nozzle that makes the ultrasonic atomizer’s spray useful in industrial applications by forming a useful spray pattern and by providing a method of propelling the droplets in a desirable pattern. This new device forms the ultrasonically atomized drops into a well defined cone or flat spray pattern which is adjustable in width and distribution.

The paper will present the underlying principle behind this new concept. It will also investigate the interaction between the resonator and shaping gas as it relates to droplet size and droplet velocity of the spray. Among other means, the discussion will concentrate on coverage information that will be collected through an optical patternation device and droplet size information.

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Introduction
The objective of these trials was to determine the effects of water flow rate and spray distance on drop size and spray characteristics of an ultrasonically atomized [1] fullcone spray pattern. Spraying Systems Co. (SSCo.) has characterized the ultrasonic nozzle by providing spray distribution, drop size distribution and velocity data at the stated test conditions. All trials were performed using an ultrasonic style nozzle at multiple water flow rates and spray heights. These nozzles provide small droplets in a fullcone pattern. The resulting spray has fine particles with very low velocities. A section of the test nozzle is displayed in Figure 1 below.

Test Instruments

The LaVision Optical Patteration Instrument
The LaVision SprayMaster system, as shown in Figure 2, is designed for the quantitative visualization of the spray process. The integrated imaging system uses a laser sheet to measure the intensity of the spray. This instrument was used to measure the geometry of the spray at various spray heights and operating conditions.

The Phase Doppler Particle Analyzer
A two-dimensional TSI/Aerometrics PDPA (Phase Doppler Particle Analyzer) system was used to acquire drop size and velocity measurements. A 300-mWatt Argon-Ion laser provided the light source. The laser was operated at an adequate power setting to overcome interference due to spray density effects. The PDPA setup and operation is illustrated in Figure 3.

The laser light transmitter and receiver were mounted on a rail assembly with rotary plates; the light receiver was oriented in a 40° forward scatter collection position. For these particular tests, a transmitting lens with a 100mm focal length and a receiving lens with a 300mm focal length were selected for optimum drop size resolution. This resulted in an optimized size range of about 0.5μm – 50μm for water drops. Further testing was conducted using a transmitting lens with a 250mm focal length and a receiving lens with a 300mm focal length, which resulted in an optimized size range of about 0.54μm – 145μm for water drops. These optical setups were used to ensure capturing the full range of droplet sizes while maintaining good measurement resolution. The particular range used for these tests was determined by a preliminary test where the D_{50.5} and the overall droplet distribution will be examined. This lens selection adequately resolved the entire droplet size range produced by the nozzles. For each test
point, a maximum of 10,000 samples were acquired. In the event that 10,000 samples were not achieved within 60 seconds the traverse would move to the next point.

**Spray Patternation with LaVision system**
The shape of the spray was interrogated at multiple water flow rates from 3 to 13cc/min and air pressures of 21 and 69kPa. The resulting spray patterns were observed to fluctuate with the liquid flow rate and air pressure. The equipment layout for this test is shown in Figure 4.

![Figure 4. Spray pattern test with LaVision system and its side view test schematic.](image)

Figure 5 shows the results of the spray pattern test at 5, 50, 100, 150, 200, 250, and 300mm from the orifice. Figure 6 shows the same type of data, but at 69kPa air pressure.

**Spray pattern observations**
The circularity and concentricity of the spray appears to vary with respect to distance from the orifice and liquid flow rate. The radius of the equivalent full cone at 3cc/min was determined to increase from approximately 6mm near the orifice to 25-40mm at the maximum measured distance of 300mm from the orifice. It is also noted that the radius of the spray decreased at greater than 250mm distance with the higher air pressure. These trends are exhibited in Figure 7 below.

![Figure 5. Spray coverage at 21kPa air pressure, 3 cc/min (left), 8 cc/min (middle), 13 cc/min (right) liquid flow rate.](image)

![Figure 6. Spray coverage at 69kPa air pressure, 3 cc/min (left), 8 cc/min (middle), 13 cc/min (right) liquid flow rate.](image)
Drop Size and Velocity by a PDPA System

Figure 3 shows the test setup for the PDPA drop size equipment. The nozzle is positioned above the laser and sprays vertically down.

Drop size: terms and definitions

The D_{V0.1}, D_{V0.5}, D_{32}, and D_{V0.9} diameters as well as the relative span factor were used to evaluate the drop size data. The drop size terminology is as follows: [2]

D_{V0.1}: is a value where 10% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value.

D_{32}: Sauter Mean Diameter (also known as SMD) is a means of expressing the fineness of a spray in terms of the surface area produced by the spray. The Sauter Mean Diameter is the diameter of a drop having the same volume to surface area ratio as the total volume of all the drops to the total surface area of all the drops.

D_{V0.5}: Volume Median Diameter (also known as VMD or MVD). A means of expressing drop size in terms of the volume of liquid sprayed. The VMD is a value where 50% of the total volume (or mass) of liquid sprayed is made up of drops with diameters larger than the median value and 50% smaller than the median value. This diameter is used to compare the change in drop size on average between test conditions.

D_{V0.9}: is a value where 90% of the total volume (or mass) of liquid sprayed is made up of drops with diameters smaller or equal to this value.

Relative span factor (RSF): is a dimensionless parameter indicative of the uniformity of the drop size distribution. RSF is defined in Equation 1 as following:

\[ RSF = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}} \]  

Droplet Size Results

The ultrasonic nozzle provides small drop size and a tight drop size distribution overall. The spray varies with the flow rate and air pressure.

At 3cc/min liquid and 21kPa air pressure, the volume mean diameter (D_{V0.5}) ranged from 20\,\mu m at 5\,mm spray distance to 44\,\mu m at 200\,mm spray distance. At 3cc/min and 69kPa, the volume mean diameter (D_{V0.5}) ranged from 16\,\mu m at 5\,mm spray distance to 46\,\mu m at 200\,mm spray distance.

At 3cc/min, drop size values are shown to increase at spray distances greater than 100\,mm as it can be seen in the Figure 8. This trend is attributed to evaporative and drift affects. Due to evaporation and drift (small particles with little momentum), the drop size statistics reflected a larger drop size average. In the low air pressure case D_{V0.1} and D_{V0.5} are close in value, whereas D_{V0.9} is significantly larger. This indicates that the spray mainly contains small droplets with a few large droplets. Due to the volumetric weight of volumetric averages a small quantity of large droplets can significantly increase the drop size statistics.

At 13cc/min and 21kPa air pressure, the volume mean diameter (D_{V0.5}) ranged from 27\,\mu m at 100\,mm spray distance to 46\,\mu m at 10\,mm spray distance (see Figure 9). At 13cc/min and 69kPa, the D_{V0.5} varied from 35\,\mu m at 100\,mm spray distance to 46\,\mu m at 10\,mm spray distance. The assumption is the D_{V0.5} value is high and close to D_{V0.9} value due to the Vortex effect that tends to limit the time of residency of the liquid on the atomizing horn: D_{V0.5} = 46\,\mu m compared to D_{V0.9} = 48\,\mu m.
At spray heights over 100mm, the same trend of increasing $D_{V0.5}$ that occurred at 3cc/min appears at 13cc/min, although the increase is not as great (see Figure 9). However, the evaporation may be lighter for two reasons. First of all the flow rate is higher and makes this phenomenon less effective. Secondly, contrary to the spray at 3cc/min, the spray at 13cc/mm contains bigger drops at 10mm ($D_{V0.5}$, 3cc/min = 16/20µm compared to $D_{V0.5}$, 13cc/min = 46/46µm). Because only small droplets are inclined to increase the evaporation, this phenomenon is mild at this higher flow rate. At the aforementioned conditions the drop size ($D_{V0.5}$) was found to be small with a tight distribution, represented by the relative span factor lower than 1, and shown in Table 1.

<table>
<thead>
<tr>
<th>Air Pressure 21kPa</th>
<th>$D_{V0.50}$ (µm)</th>
<th>Relative Span Factor</th>
</tr>
</thead>
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<tr>
<td>3cc/min</td>
<td>20.1</td>
<td>0.91</td>
</tr>
<tr>
<td>13cc/min</td>
<td>45.7</td>
<td>0.87</td>
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Table 1. $D_{V0.5}$ and RSF at 5/10mm spray height, 21kPa, 3cc/min and 13cc/min.

**Velocity results**

Velocity data was also obtained throughout testing. The velocity is relatively low (less than 4m/s) in any configuration. From Figure 10, it is evident that at distances greater than 100mm the velocity has largely stabilized. This is attributed to in part to evaporative affects.

**Conclusions**

The results of these trials indicate a full cone spray pattern, evident from Figures 5 & 6. The drop size characteristics are shown in Table 2 below with corresponding Figures 8 and 9.

<table>
<thead>
<tr>
<th>Spray ht. (mm)</th>
<th>$D_{V0.10}$ 3cc/min</th>
<th>$D_{V0.50}$ 3cc/min</th>
<th>$D_{V0.90}$ 3cc/min</th>
<th>$D_{V0.10}$ 13cc/min</th>
<th>$D_{V0.50}$ 13cc/min</th>
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</table>

Table 2. Droplet size table summary at 21kPa

This series of tests show that flow rate, shaping air pressure, and spray height are factors that affect spray performance. These tests were conducted with water and evaporation has an affect on spray performance, especially on the smallest droplets. The vortex effect, which tends to limit the time of residency the liquid has on the atomizing horn may increase droplet size at the higher flow rates. Increasing drop size and stabilizing velocity can also be attributed to evaporative effects. Spraying Systems Co. is committed to ultrasonic spray nozzle technology and to provide solutions for industrial and life sciences applications.

**References**


**Acknowledgement**

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