Characteristics of Spray Deposit Pattern and Flow Rate in the Air-Center Nozzle System

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Air-center nozzle의 噴霧散布度와 噴霧量의 特性

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SUMMARY

The air-center nozzles, being specially designed to supply air into the central part of water stream at seven levels of air volume, were tested for spray deposit pattern and flow-rate at each of the twelve pressure levels ranging from 0.35 kg/cm² (5 psi) to 6.33 kg/cm² (90 psi) in comparison with those of standard nozzles.

The air-center nozzles produced comparatively more stable spray deposit patterns than the standard nozzles.

The spray deposit patterns of the air-center nozzle were concentrated gradually in the central region with increase of air volume as a component of spray mixture.

The degree of concentration of spray deposit on the central region from the air-center nozzle was higher than that of the standard nozzle, which suggested the possibility of obtaining farther travel distance spraying system at a given performance level.

The flow rate of the air-center nozzle was not as much as that of the standard nozzle due to the air within certain limits.

The rate of decrease of water flow became smaller with an increase in operating pressure although it changed rapidly in the beginning stage, ranging up to two or three percent of the air flow rate due to the compressive properties of air.

INTRODUCTION

There has been increasing interest in the quality of agricultural sprays, particularly in the evenness of distribution with adequately sized droplets.

Many previous works1,2,4,5,7,8) have pointed out that small droplets with an even distribution give greater coverage and more chance of biological effectiveness at lower dosage rates.

Several methods of driving spray droplets or particles to their targets have been applied depending upon the characteristics of the atomizing system including the angle of spray, spray deposit pattern, and flow rate in the relation of the conditions of their targets.

Droplets15) emitted from hydraulic nozzle systems travel to the target with their own kinetic energy, therefore large droplets travel farther than small droplet across deposit pattern meanwhile the droplets16) emitted from the rotary nozzle

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system are driven by air movement as airborne droplets, and so large droplets fall out in the area closer to the nozzle in spite of the large volume air delivered by the air blast sprayer.

As one approaches a complete film of liquid over the targets run-off results.

This is a waste of chemicals and a hazard to the soil with poor deposit distribution in row crops, and marked difference between deposit distributions in upper and lower parts of large trees. A desirable pattern is hardly achieved by present applicators like the gun type nozzle and the air-blast sprayer in long distance spraying application.

The trajectories of airborne droplets may be influenced by meteorological conditions, particularly cross winds during the transportation, and so the droplets whose trajectories have changed from the targets affect unwanted targets through drift, contaminate the ecosystem, and result in poor spray deposit distribution.

Secondly, flow-rate is an important factor in efficiency with regard to time and labor saved with a reasonable discharge in relation with the power requirement.

The flow-rates emitted from hydraulic nozzles are usually proportional to square root of the pressure, and the flow-rates of gas-atomizing nozzles are very small since gas-atomizing nozzles require more gas to produce much smaller drops than pressure nozzles.

The static pressure drop accompanying the isothermal two-component flow of air and water was much larger than the pressure drop for either one alone in the horizontal pipe according to Martinelli. Therefore the flow-rate of water must be maintained at a certain level with a reasonable ratio between the two fluids in regard to the power requirement.

This study has tried to examine the peculiar characteristics of the air-center nozzle system on the spray deposit distribution and the flow-rate in order to find a suitable application method giving the best coverage over the target.

**EQUIPMENTS AND METHODS**

**Equipments**

The experimental apparatus was framed as shown in Figure 1 in order to examine the peculiar characteristics of the developed aircenter nozzle system on the spray deposit distribution and flow-rate.

1) Operating pressures of the spray liquid and air could be controlled sensitively at optimal pressure levels by a pressure regulator at ranges from 0.21 kg/cm² (3 psi) to 8.44 kg/cm² (120 psi) and checked by pressure gages made by Floyd.

2) The roller pump, model 6-roller Back Port made by Delavan, was connecting to the water chamber and its flow-rate was 32 liter per minute at 550 RPM.

3) Rotameters, size 10 and 18, made by Rotameter Manufacturing Co. Ltd., Croydon England, were used for the measurement of the flow-rates of water, and Tri-Flat Variable-Area Flow Meters, made by Fisher & Porter, were equipped for measurement of the flow-rates of air, and a pressure regulator, SCOVILL, made by Schrader, was used to control the pressure of the air from the air accumulator.

4) The boom was equipped with another Spraying Systems Fulljet nozzle, No. 1/8 G 1.5 with a rated capacity of 1.10 lit/min. and a spray angle of 62 degree at 2.81 kg/cm² (40 psi), or a Spraying Systems Fulljet nozzle, No. 1/8 G 3 with a rated capacity of 2.16 lit/min. and a spray angle 62 degree at 2.81 kg/cm² (40 psi).

The nozzles (figure 2) so-called 'Air-center Nozzle' which were specifically designed so that the mixing of the liquid and the air took place completely in the whirl chamber for a better atomization, they were used.

The patternator in figure 3 was used to obtain deposits across the spray patterns. It was made in the Work Shop of the Faculty of Engineering, Melbourne University, according to British Stan-
Fig. 1. Schematic diagram of the sprayer apparatus.
Two sizes of nozzles, No. 1/8 G 1.5 and No. 1/8 G 3, as standard nozzles were tested. Each was operated at twelve pressure levels of 0.35 (5), 0.70 (10), 1.06 (15), 1.41 (20), 1.76 (25), 2.11 (30), 2.81 (40), 3.52 (50), 4.22 (60), 4.92 (70), 5.62 (80), and 6.33 kg/cm² (90 psi).

The nozzles were also tested separately at the twelve pressure levels above. At each pressure level, the air was injected into the liquid stream through No. 17 (dia. 1.42 mm), No. 18 (dia. 1.20 mm), No. 19 (dia. 1.10 mm), No. 20 (dia. 0.90 mm), No. 21 (dia. 0.80 mm), No. 23 (dia. 0.60 mm), and No. 26 (dia. 0.45 mm) air needles to investigate the effects of air as a component of mixture on the deposit pattern and the flow rate to compare them at a given pressure level.

Two size air-center nozzles were tested repeatedly to clarify the effects of air at a water pressure of 2.11 kg/cm² with air pressures of 2.81 to 3.52 kg/cm², and then at a water pressure of 4.22 kg/cm² with air pressures of 4.92 to 5.62 kg/cm² respectively.

Spray height was 45 cm and the time of duration required to fill the measuring flasks of 50 cc positioned at ends of each sections with sprayed water was carefully measured by a stop watch.

Before the primary experiment was carried out, the measuring cylinder and the rotameter were examined to evaluate the accuracy of the flow rates.

Their deviations were less than one percent, the allowable limit.

Air flow rate was measured by Tri-Finet Variable Area Flow Meters with black ball and silver ball according to the levels of flow rate. It was converted to the standard volume at 1.033 kg/cm³ & 20°C to evaluate the volumetric ratio between air and water.

Measurements were repeated three times.

All data were converted into the unit volume per one minute. The arrangements of the experiment were according to randomized block designs.

All experiments were conducted in still air.
The uniformity of the spray deposit pattern distribution was assessed by the coefficient of uniformity (CU). Calculations of CU were based on the liquid volume of 16 sections of the tray used.

The coefficient of uniformity is a transformation of the coefficient of variation and it is derived from the assumption that the worst possible spray pattern exists when all of the spray is deposited at one point and that the best possible pattern exists when the deposit area has the same concentration at all points.

\[
CU(\%) = \left( \frac{SD_{\text{max}} - SD_{\text{observed}}}{SD_{\text{max}}} \right) \times 100
\]

The maximum standard deviation can be calculated by the mean concentration multiplied by the square root of the sample size as follows;

\[
SD = \sqrt{\frac{1}{n-1} \left[ \sum X_i^2 - \frac{(\sum X_i)^2}{n} \right]}
\]

\[
SD^2 = \frac{1}{n-1} \left[ \sum X_i^2 - \frac{(\sum X_i)^2}{n} \right]
\]

\[
= \frac{\sum X_i^2 (\sum X_i)^2}{n(n-1)}
\]

if all of the spray is deposited at one point,

\[
\sum X_i^2 = (\sum X_i)^2
\]

Substituting these into \( X^2 \)

\[
SD_{\text{max}}^2 = \frac{X^2}{n-1} - \frac{X^2}{n(n-1)} = \frac{X^2}{n}
\]

\[
SD_{\text{max}} = \frac{X}{\sqrt{n}}, \quad \text{taking } \bar{x} = \frac{X}{n}
\]

\[
SD_{\text{max}} = \bar{x} \sqrt{\frac{X}{n}}
\]

The minimum value of CU occurs when the observed standard deviation is the largest. The maximum value of CU occurs when the observed standard deviation of the deposits is zero. Therefore CU is zero percent when the worst possible distribution exists and it is 100 percent when the distribution is the best. When comparing the patterns of different spray nozzles, the range of CU values is from 0 to 100 percent. Significant differences were analyzed by Duncan's new multiple-range test at the 5 percent level to determine where the significant differences were.

**RESULTS AND DISCUSSION**

Analyses of results were arranged into two parts; the spray deposit patterns and flow rates.

A mixture consisting of water and air has two compatible physical characteristics, that is, water is an incompressible fluid while air is a compressible fluid, therefore their volume were assessed under standard conditions.

**Spray Deposit Pattern**

The operating pressure had a significant effect on the patterns, including spray angles from the Fulljet type standard nozzles, under pressures of less than 1.06 kg/cm² which might be a critical pressure in forming of a stable deposit pattern as shown in figure 4 (a).

The spray deposit pattern became stable, in general, from the pressure of 1.06 kg/cm² and upward.

Meanwhile the operating pressure had little effect on the patterns from the air-center nozzles as shown in figure 4 (b) with the pressures from 0.35 kg/cm² to 6.33 kg/cm². This meant that the air-center nozzles produced more stable spray deposit patterns than the standard nozzles.

Coefficients of uniformity in Table 1 indicates that spray deposit had been relatively concentrated on the central region from the large size standard nozzle of No. 1/8 G 3 when operated under the pressures less than 1.76 kg/cm² (25 psi), while the same results came from the large size air-center nozzle of No. 1/8 G 3 operated at the pressures less than 1.06 kg/cm² (15 psi).

The effects of air were highly significant on spray deposit patterns as indicated in figure 5 which shows that spray deposit patterns had been
*Allows marked liquid center line.

Distance from nozzle axis, cm

Fig. 4(a). Spray deposit distributions by standard nozzle (No. 1/8 G 1.5) at height of 45 cm.
Fig. 4(b). Spray deposit distributions by air-center nozzle (No 1/8 G 1.5) equipped with air needles at height of 45 cm.
Lee and Hur: Characteristics of Spray Deposit Pattern and Flow Rate in the Air–Center Nozzle System become more concentrated in the central region with an increase of the amount of air.

Table 1. Coefficients of uniformity for standard nozzles and air–center nozzles.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Pressure, kg/cm²</th>
<th>0.35</th>
<th>0.70</th>
<th>1.06</th>
<th>1.41</th>
<th>1.76</th>
<th>2.11</th>
<th>2.81</th>
<th>3.52</th>
<th>4.22</th>
<th>4.92</th>
<th>5.62</th>
<th>6.33</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 G 1.5 Standard nozzle</td>
<td>77.66</td>
<td>78.94</td>
<td>77.06</td>
<td>78.58</td>
<td>77.68</td>
<td>78.82</td>
<td>78.25</td>
<td>78.24</td>
<td>78.39</td>
<td>78.50</td>
<td>79.42</td>
<td>78.87</td>
<td>78.37</td>
<td></td>
</tr>
<tr>
<td>1/8 G 1.5 Air–center nozzle</td>
<td>67.47</td>
<td>72.47</td>
<td>73.49</td>
<td>73.23</td>
<td>73.42</td>
<td>72.97</td>
<td>72.33</td>
<td>72.20</td>
<td>72.22</td>
<td>72.22</td>
<td>71.79</td>
<td>72.40</td>
<td>72.17</td>
<td></td>
</tr>
<tr>
<td>1/8 G 3 Standard nozzle</td>
<td>59.61</td>
<td>67.17</td>
<td>68.79</td>
<td>72.34</td>
<td>74.49</td>
<td>75.73</td>
<td>75.79</td>
<td>75.98</td>
<td>75.98</td>
<td>76.32</td>
<td>76.71</td>
<td>75.44</td>
<td>72.86</td>
<td></td>
</tr>
<tr>
<td>1/8 G 3 Air–center nozzle</td>
<td>66.40</td>
<td>67.35</td>
<td>68.74</td>
<td>69.40</td>
<td>69.35</td>
<td>69.53</td>
<td>68.78</td>
<td>68.96</td>
<td>68.70</td>
<td>68.83</td>
<td>68.50</td>
<td>68.27</td>
<td>68.57</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 5. Spray deposit distributions by air–center nozzle(1/8 G 1.5) at different pressures.

*Allows marked liquid center line
Figure 6 again definitely shows that the spray deposit pattern from the air-center nozzle system was highly concentrated on the central region more than that of the standard nozzle.

This suggested the possibility of getting of a farther travel distance spraying system at a given performance level.

The results of this study were almost same as the previous work\(^8\) of existing air nozzles on the spray deposit distribution.

Table 2 and 3 confirmed again that the coefficients of uniformity decreased with either an increase in air pressure or an increase in air volume, which meant that the spray deposit pattern had become narrower with an increase in air volume as a component of spray mixture as shown in figure 6.

**Flow Rates of Water and Air**

The mean values of flow rates from standard nozzles were calculated from three measurements at each pressure level in the range of 0.35kg/cm\(^2\) (5 psi) through 6.33kg/cm\(^2\) (90 psi).

The flow rates of air-center nozzles took their average values from three measurements at each of the twelve pressure levels and the mean values

<table>
<thead>
<tr>
<th>Standard nozzle</th>
<th>No. 26 air needle nozzle</th>
<th>No. 23 air needle nozzle</th>
<th>No. 21 air needle nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>210</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>190</td>
<td>160</td>
<td>130</td>
<td>100</td>
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<td>140</td>
<td>110</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>90</td>
<td>60</td>
<td>30</td>
<td>0</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>No. 20 air needle nozzle</th>
<th>No. 19 air needle nozzle</th>
<th>No. 18 air needle nozzle</th>
<th>No. 17 air needle nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>210</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>190</td>
<td>160</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>140</td>
<td>110</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>90</td>
<td>60</td>
<td>30</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fig. 6. Average spray deposit distributions by air-center nozzles (1/8 G 1.5) at pressures from 0.35 to 6.33 kg/cm\(^2\).**
Table 2. Coefficients of uniformity for air-center nozzles at pressures of 0.35 to 6.33 kg/cm².

<table>
<thead>
<tr>
<th>Nozzle Size</th>
<th>Standard nozzle</th>
<th>No. 26 air needle nozzle</th>
<th>No. 23</th>
<th>No. 21</th>
<th>No. 20</th>
<th>No. 19</th>
<th>No. 18</th>
<th>No. 17</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 G 1.5</td>
<td>78.69</td>
<td>74.25</td>
<td>72.79</td>
<td>70.63</td>
<td>70.57</td>
<td>70.76</td>
<td>69.46</td>
<td>67.44</td>
<td>70.84*</td>
</tr>
<tr>
<td>1/8 G 3</td>
<td>74.03</td>
<td>72.77</td>
<td>72.25</td>
<td>68.00</td>
<td>68.11</td>
<td>67.29</td>
<td>65.14</td>
<td>61.75</td>
<td>67.90*</td>
</tr>
</tbody>
</table>

* is average value of needle nozzles.

Table 3. Coefficients of uniformity for air-center nozzles (1/8 G 1.5) at different pressures.

<table>
<thead>
<tr>
<th>Pressure, kg/cm²</th>
<th>No. 26 Air-needle nozzle</th>
<th>No. 23</th>
<th>No. 21</th>
<th>No. 20</th>
<th>No. 19</th>
<th>No. 18</th>
<th>No. 17</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>73.71</td>
<td>73.04</td>
<td>71.65</td>
<td>71.60</td>
<td>71.53</td>
<td>69.70</td>
<td>68.10</td>
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<td></td>
<td>73.29</td>
<td>71.52</td>
<td>70.30</td>
<td>70.81</td>
<td>69.37</td>
<td>62.82</td>
<td>63.59</td>
<td>68.81</td>
</tr>
<tr>
<td></td>
<td>73.16</td>
<td>71.13</td>
<td>70.41</td>
<td>70.08</td>
<td>68.00</td>
<td>61.70</td>
<td>58.10</td>
<td>67.51</td>
</tr>
<tr>
<td>4.22</td>
<td>73.88</td>
<td>73.46</td>
<td>70.45</td>
<td>70.11</td>
<td>70.38</td>
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<td>70.66</td>
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<tr>
<td></td>
<td>71.96</td>
<td>71.65</td>
<td>68.31</td>
<td>67.34</td>
<td>67.14</td>
<td>64.41</td>
<td>61.63</td>
<td>67.49</td>
</tr>
<tr>
<td></td>
<td>71.18</td>
<td>70.76</td>
<td>66.91</td>
<td>66.58</td>
<td>66.18</td>
<td>60.69</td>
<td>57.54</td>
<td>65.69</td>
</tr>
<tr>
<td>Average</td>
<td>72.86</td>
<td>71.93</td>
<td>69.67</td>
<td>69.42</td>
<td>68.77</td>
<td>64.65</td>
<td>62.79</td>
<td></td>
</tr>
</tbody>
</table>

of flow rates at each pressure level were derived from measurements through seven sizes of pipes of air.

The mean flow volumes of the standard nozzle and the air-center nozzle, No. 1/8 G 1.5, were plotted against pressure levels as shown in figure 7.

The curve lines were agreeable to the relevant works3,9 in which the flow rate is almost proportional to the square root of the pressure.

The flow rates of the air-center nozzles did not reach those of the standard nozzles due to the air volume in the mixture of the spray liquid within certain limits.

The flow rates of air being attained from various sizes of pipes were plotted against the operating pressures in figure 8, and they were very slightly curved.

The physical properties of flow-rate between air and water showed some difference in figures 7 and 8. Namely, air is a compressive fluid and water is an uncompressive fluid.

Figure 9 shows correlations of the flow rates between water and air from the air-center nozzle No. 1/8 G 1.5 with operating pressure levels from 0.70 kg/cm²(10 psi) through 6.33 kg/cm²(90 psi).

Figure 10 simplified again the correlation between water and air on the flow-rates of figure 9 as percents based on the criterion in which the flow-rate of water from standard nozzle was 100 percent.

The rate of decrease of water-flow rapidly increased when the percent of air-flow approached two to three percent and thereafter it gradually became dull.

The rate of decrease of water-flow became smaller with an increase in the operating pressure.
Fig. 7. Correlations between water flow rate and pressure on nozzle of 1/8 G 1.5.

Fig. 8. Correlations between air flow rate and pressure on air-center nozzle (1/8 G 3).

Fig. 9. Correlations of flow-rates between water and air by air-center nozzles (1/8 G 1.5)
due to compressive properties of air in the air-center nozzle.

**Fig. 10.** Correlations of flow-rate percents between water and air by air-center nozzles (1/8 G 1.5).

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**LITERATURE CITED**