Drop size distribution measurement of ISO nozzles by shadowgraphy method

Nicolas De Cock, Mathieu Massinon, Sofiene Ouled Taleb Salah, Benoît Mercatoris, Frédéric Lebeau

Université de Liège, Gembloux Agro-Bio Tech
Agricultural spray application

**Deposition**
From the nozzle to the plant
- Effect of the size on droplets driftability

**Retention**
Droplet impacts on the plant surface
- Effect of the droplets energy on the retention

\[ We = \frac{\rho v^2 l}{\sigma} \]
Spray characterization techniques

- Laser diffraction spectrometry (LDS)
  - Droplet size
- Phase Doppler Anemometry (PDA)
  - Droplet size and speed
- Particle/Drop Image Analysis (PDIA)
  - Based on image analysis
  - Droplet size and speed

Need coherent light (laser)
- High cost
- Based on optic theory
- Require liquid optical properties
Objective

Validation of a versatile, low cost and accurate spray characterization tool based on high speed imaging

Method

Assess the method capability to segregate nozzle class boundaries (VF/F, F/M, ...)

19/05/2015
Nicolas De Cock
Image acquisition set-up

- 8-bit PIV camera
- 72 W LED panel
- Acquisition of picture in PIV mode (double frame)
- Scan of ¼ of the spray
Image processing method

Overall spray characteristics is set by summing each droplet characteristic.
Drops localization

Average background subtraction

Gradient computation

Localization of the drop boundaries by applying a Canny filter
Out of focus drops rejection

Drop shadow boundaries present various levels of sharpness

\[ \text{Sharpness} \propto \text{Gradient intensity at the boundary} \]
Out of focus drops rejection

- Determination of focus parameter threshold

\[ \text{Focus parameter} = \frac{\text{grad}_{\text{bound}}}{I_{\text{object}} - I_{\text{back}}} \]

Oblique stream of monosized drops

Relative error on drop diameter measurements
Velocity measurement

- Droplet tracking based on:
  - Droplet size
  - Most probable displacement

\[ D_{\text{max}} = v_{\text{max}} \Delta t \]

\( \theta \) deviation in respect to the main flow
Sampling probability

Residential time

Size of the probe volume

Probe volume

\[ \text{time} \downarrow \text{when } v \uparrow \]

\[ \text{size} \downarrow \text{when } d \uparrow \]
Correction of the drop size distribution

\[ \text{Correction} = \frac{\nu}{(FOV_{cor} \cdot DOF)} \]

\[ \text{Sampling probability} \propto \frac{PV_{size}}{v_d} \]

Correction
### Measurements

#### Scan of 6 nozzles defining the droplet size class boundaries

<table>
<thead>
<tr>
<th>Class boundary</th>
<th>Nozzle type</th>
<th>Pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF/F</td>
<td>TeeJet TP 110 01</td>
<td>4.5</td>
</tr>
<tr>
<td>F/M</td>
<td>TeeJet TP 110 03</td>
<td>3.5</td>
</tr>
<tr>
<td>M/C</td>
<td>TeeJet TP 110 06</td>
<td>2.5</td>
</tr>
<tr>
<td>C/VC</td>
<td>TeeJet TP 80 08</td>
<td>2.5</td>
</tr>
<tr>
<td>VC/XC</td>
<td>TeeJet TP 65 10</td>
<td>1.5</td>
</tr>
<tr>
<td>XC/UC</td>
<td>TeeJet TP 65 15</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Spatial distribution of the droplets

- Highest droplet density at the spray center
- Ellipsoidal shape (~1-10 for the 110 03)

110 03 @ 3 Bars
Spatial distribution of the droplets

- Linear decrease of the droplet density with the distance to the spray center
- Weak effect of the nozzle
- Less than 5% of the droplet measured in the last scanning line
Cumulative drop size distribution

<table>
<thead>
<tr>
<th>Class Boundary</th>
<th>Dv10 (µm)</th>
<th>Dv50 (µm)</th>
<th>Dv90 (µm)</th>
<th>Droplet count</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF/F</td>
<td>107</td>
<td>154</td>
<td>232</td>
<td>95398</td>
</tr>
<tr>
<td>F/M</td>
<td>158</td>
<td>239</td>
<td>414</td>
<td>46756</td>
</tr>
<tr>
<td>M/C</td>
<td>186</td>
<td>304</td>
<td>532</td>
<td>39947</td>
</tr>
<tr>
<td>C/VC</td>
<td>225</td>
<td>375</td>
<td>612</td>
<td>28817</td>
</tr>
<tr>
<td>VC/XC</td>
<td>274</td>
<td>479</td>
<td>786</td>
<td>15552</td>
</tr>
<tr>
<td>XC/UC</td>
<td>305</td>
<td>532</td>
<td>927</td>
<td>20084</td>
</tr>
</tbody>
</table>
Conclusions

- An image processing method has been presented
- The spatial analysis of the data showed that the scanning method is appropriate for flat fan sprays
- The imaging method is able to segregate the droplet size class boundaries

Further work

- Computation of the flow rate by integrating the measurements over the spray