Knowing the Fire Sprinkler Spray

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The Science of Suppression
FireSEAT
Edinburgh, Scotland UK

Ning Ren, Chi Do, and Andre Marshall

Sponsors: FM Global, NSF
Overview

• Introduction
  • How do we quantify sprinkler sprays?

• Objective
  • Evaluate discharge characteristics through measurements

• Measurements and Results
  • Stream Formation
  • Stream Breakup
  • Initial Spray
  • Dispersed Spray

• Summary
Introduction – Sprinkler Spray Example

**Tyco D3**

**K = 81 lpm bar**$^{-1/2}$

**P = 1.4 bar**
Introduction – Sprinkler Spray Characteristics

- How do we quantify sprinkler sprays?

### Spray Discharge

<table>
<thead>
<tr>
<th>Discharge Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{50}$ (mm)</td>
<td>2.1</td>
</tr>
<tr>
<td>$u_{inj}$ (m/s)</td>
<td>10.5</td>
</tr>
<tr>
<td>$\theta_{inj}$ (deg)</td>
<td>95</td>
</tr>
<tr>
<td>$q''$ (mm/min)</td>
<td>1.5</td>
</tr>
<tr>
<td>$r_{cov}$ (m)</td>
<td>4</td>
</tr>
</tbody>
</table>

### Drop by Drop

<table>
<thead>
<tr>
<th></th>
<th>$r$ (m)</th>
<th>$\theta$ (deg)</th>
<th>$\psi$ (deg)</th>
<th>$d$ (mm)</th>
<th>$u$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>95</td>
<td>100</td>
<td>2.3</td>
<td>10.2</td>
</tr>
<tr>
<td>2</td>
<td>0.35</td>
<td>99</td>
<td>92</td>
<td>0.5</td>
<td>9.8</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>92</td>
<td>275</td>
<td>3.1</td>
<td>8.9</td>
</tr>
<tr>
<td>4</td>
<td>0.35</td>
<td>90</td>
<td>117</td>
<td>1.2</td>
<td>11.1</td>
</tr>
<tr>
<td>...</td>
<td>....</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1,000,000</td>
<td>0.35</td>
<td>97</td>
<td>342</td>
<td>0.3</td>
<td>10.7</td>
</tr>
</tbody>
</table>
Objective

- **Evaluate discharge characteristics** from fire suppression devices from **measurements** to support CFD model and fire suppression product development (nozzle and system)
Measurements – Overall Methodology

Objective: Establish method for computationally introducing measured or predicted initial drop location, size, and velocity and simulating interaction with the continuous phase.

Objective: Characterize the geometries and flow paths of the thin streams created by the sprinkler jet and deflector.

Objective: Develop a methodology and model to predict the initial spray from the fire sprinkler geometry and injection conditions.

Objective: Characterize the initial spray from the sprinklers.
Planar Laser Induced Fluorescence (PLIF)

- Qualitative view of sheet topology.
- Difficulty measuring exact sheet thickness due to deflector surface reflections.
- High speed camera would provide breakup visualization.
Results – Stream Formation

- Two distinct streams are formed.
- Flow split between these streams governs the sheet thickness and the resulting drop size.
Approach / Results – Stream Formation

Short Time Exposure Photography

- Qualitative view of sheet topology
Short Time Exposure Photography

Approach – Stream Breakup

Canon 12-bit 3.4 Mpixel Digital SLR Camera
Results – Stream Breakup

$$X_{sheet} = \left(\frac{\rho_a}{\rho_l}\right)^2 \left(\frac{We}{\beta^3 \gamma}\right)$$

Ambient Condition

Injector Disturbances

Modified Weber Number

Sheet Break-up Distance, $2r_{ac}/D_o$

Scaling Parameter, $X_{sheet}$
Approach – Initial Spray

Shadowgraph/PTV (Drop Size/Velocity) Measurements
Approach – Initial Spray

Area used: 150X150 mm

Image size: 170X170 mm

Minimum drop resolved: ~0.2mm
Results – Initial Spray

Std Nozzles (D3): ● $D_o = 6.2$ mm - tine, ● $D_o = 11.0$ mm – tine, ◯ $D_o = 6.2$ mm - slot, ◯ $D_o = 11.0$ mm - slot; Basis Nozzles: ■ $D_o = 3.2$ mm, ■ $D_o = 6.2$ mm, □ $D_o = 9.5$ mm

Drop Formation

$$X_{drop} = \left( \frac{\rho_a}{\rho_l} \right)^{1/2} f_o \left( \frac{We}{\beta^3 \gamma} \right)$$
Results – Initial Spray Description

Tyco D3

\[ K = 81 \text{ lpm bar}^{-1/2} \]

\[ P = 1.4 \text{ bar} \]

Sprinkler Discharge

- Physically rational compact description of spray.
- Provides a framework for spray evaluation and insight.
- 48 coefficients describe (and can generate) the 3D stochastic spray.
- 15 first order coefficients describe primary spray characteristics.

### Peak (Gaussian)

<table>
<thead>
<tr>
<th>Volume Probability Density (for location)</th>
<th>Drop Size</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_v(\theta, \psi, t)$</td>
<td>$d_{v,50} / D_o$</td>
<td></td>
</tr>
<tr>
<td>$D_o = 11$ mm</td>
<td>$\Gamma$ (distribution width)</td>
<td>$u / U$</td>
</tr>
<tr>
<td>$t$</td>
<td>$s$</td>
<td>$t$</td>
</tr>
<tr>
<td>Avg</td>
<td>$L_0$</td>
<td>0.004</td>
</tr>
<tr>
<td>$F_0$</td>
<td>0.86</td>
<td>0.54</td>
</tr>
<tr>
<td>$\theta (\circ)$</td>
<td>102</td>
<td>107</td>
</tr>
<tr>
<td>$\sigma (\circ)$</td>
<td>3.4</td>
<td>2.6</td>
</tr>
</tbody>
</table>

### Shape

<table>
<thead>
<tr>
<th>$L_i / L_0$</th>
<th>0.59</th>
<th>0.69</th>
<th>-0.012</th>
<th>0.33</th>
<th>-0.085</th>
<th>0.016</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_2 / L_0$</td>
<td>-0.95</td>
<td>-1.1</td>
<td>0.48</td>
<td>0.052</td>
<td>0.053</td>
<td>-0.36</td>
</tr>
<tr>
<td>$L_3 / L_0$</td>
<td>0.46</td>
<td>-0.027</td>
<td>0.067</td>
<td>0.60</td>
<td>0.016</td>
<td>0.40</td>
</tr>
<tr>
<td>$L_4 / L_0$</td>
<td>-0.31</td>
<td>0.80</td>
<td>0.097</td>
<td>-0.17</td>
<td>0.063</td>
<td>0.046</td>
</tr>
<tr>
<td>$L_5 / L_0$</td>
<td>0.26</td>
<td>-0.63</td>
<td>0.43</td>
<td>0.56</td>
<td>0.037</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Tyco D3

$K = 81$ lpm bar$^{-1/2}$

$P = 1.4$ bar
Results – Initial Spray

Fourier Coefficients

<table>
<thead>
<tr>
<th>Shape</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.333</td>
<td>0.551</td>
<td>-0.276</td>
</tr>
</tbody>
</table>

Volume Probability Density (for location)

$V(t, s) = \frac{f_v(\psi_s)}{f_v(\psi_t)} = 0.86$

Tyco D3

$K = 81 \text{ lpm bar}^{-1/2}$

$P = 1.4 \text{ bar}$
Malvern Drop Size Measurements

Malvern Spraytec Analyzer (Light Diffraction Technique)

Local Measurements

Local Drop Size Distribution

- Drop size limit (~ 0.8 mm)
Results – Drop Size Comparison

Tyco D3
K = 81 lpm bar$^{-1/2}$

P = 0.7 bar

P = 1.4 bar
Tyco D3
K = 81 lpm bar$^{1/2}$
P = 1.4 bar
2.9 mm/min

Results – Dispersed Spray

Initiation Sphere

Patternation (z = -1 m)

Measurement

Prediction

![Images of spray patterns and measurement predictions]

Patternation (z = -1 m)

Volume Flux, $q'q''$

Radial Location, r/R
Summary

- Focused measurements provide insight into the discharge characteristics of sprinkler sprays.
- Qualitative and quantitative measurement methods are available to explore sprinkler spray behavior from stream formation to the dispersed spray.
- These measurements provide insight into basic features of the spray (images/comprehensive framework), relationship with nozzle geometry (scaling laws), CFD modeling input (detailed measurements), and suppression performance (volume flux measurements).
Future Work - Measurements

Near Field Patternation Measurements

Initiation Sphere

350 mm

50 mm

Tyco D3

\[ K = 81 \text{ lpm bar}^{-1/2} \]

\[ P = 0.7 \text{ bar} \]
# Acknowledgements

### FM Global Sponsors
- Dr. Bert Yu
- Dr. Sergey Dorofeev

### UM Fire Suppression Spray Group

<table>
<thead>
<tr>
<th>Current</th>
<th>Graduates</th>
</tr>
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<tbody>
<tr>
<td>Dr. Howard Baum</td>
<td>Mr. Ning Ren</td>
</tr>
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<td>Dr. Ning Ren</td>
<td>Mr. Paolo Santangelo</td>
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<td>Mr. Chi Do</td>
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<tr>
<td>Ms. Yinhui Zheng</td>
<td>Mr. Andrew Blum</td>
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<tr>
<td>Mr. Giovonni Bendetto</td>
<td>Ms. Di Wu</td>
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<td>Ms. Delphine Guillemin</td>
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