Characterization of Multiple Plume Fuel Injectors Using Extinction Tomography

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Motivation

- Multiple plume fuel injectors are increasing used in GDI systems, diesel engines, and urea dosers
- Wide variation in injector performance, even from the same manufacturer
- Several methods exist to characterize single plume or even two plume fuel injectors
- There is no SAE or other standards for characterization of multiple plume injectors
Objective

- Develop a reliable and accurate method to characterize multiple plume injectors.
- Capability to analyze injectors in < 5 seconds
- Propose key spray parameters that can be used for developing quality audit parameters
- Implementation on production floor
Statistical Extinction Tomography

Several sizes for sprays ranging from 25 mm to 250 mm footprint

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Principle of Operation of Patternator

- Tomography of extinction data with a sampling frequency of 10 KHz

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Characteristics of Data

- The data can be either transient or ensemble average of drop surface area per unit volume
- Differs from mechanical patternator (which is time average of mass flux)
- Spatially and temporally resolved
- Triggered with injection pulse to study pulse to pulse variation
- Injection time of ~ 1 to 2 ms (10 to 20 frames)
Importance of surface areas

Correlation of fuel evaporation with parameters

Drop size = 0.681  
Velocity = -0.239  
Mass flux = 0.903  
Surface area density = 0.962

Surface area density is the most important parameter to measure if you are interested in obtaining the amount of fuel evaporated at any location in a spray.
Sample Results
Test Details

- Two injectors (5 orifice and 6 orifice)
- Ambient pressure of 101 KPa
- Fuel temperature of 20 °C
- Baseline E-10 gasoline fuel
- Injection pressures of 10 and 15 MPa
- All data based on 5 injection events lasting 1.5 ms each
Surface area distribution (5 holes)

- Quantitative values of surface areas (+/- 2%)
- Drop surface areas greater at 15 MPa (smaller drops)
- Very similar for both pressures

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### Plume Analysis (5 holes)

<table>
<thead>
<tr>
<th>Plume ID</th>
<th>Center R (mm)</th>
<th>Center q (deg)</th>
<th>Center X (mm)</th>
<th>Center Y (mm)</th>
<th>Plume Angle (deg)</th>
<th>Total Area (mm²)</th>
<th>% in Plume</th>
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<tbody>
<tr>
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<td>22.9</td>
<td>35.9</td>
<td>18.5</td>
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<td>-17.2</td>
<td>123.8</td>
<td>21</td>
<td>20.7</td>
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</tbody>
</table>

Total (plume separation at 7.0%)

- Centroids within 200 microns
- Plume angles within 1/2 degree
- % distribution in plumes within 1%
- Improves with more samples

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Surface area distribution (6 holes)

- Slightly smaller footprint
- Higher surface areas than 5 hole injector
- Similar trends with pressure

15 Mpa

10 Mpa

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## Plume Analysis (6 holes)

<table>
<thead>
<tr>
<th>Plume ID</th>
<th>Center R (mm)</th>
<th>Center $\theta$ (deg)</th>
<th>Center X (mm)</th>
<th>Center Y (mm)</th>
<th>Plume Angle (deg)</th>
<th>Total Area (mm²)</th>
<th>% in Plume</th>
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<td>15.1</td>
<td>11</td>
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</tbody>
</table>

Total (plume separation at 15.9%)

- All analysis is automated
- Only input required is number of plumes
- Any of the above can be used for quality audit

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Sample Repeatability

- Total surface area of all the drops within a 1 mm height in the plane
- Standard deviation in all cases (other than the first sample) is <5%
- If total surface area over entire injection period is taken, standard deviation is less than 0.5%

Ideal variable for quality audit of different nozzles
Comparison with Mechanical Patternator

- Mechanical patternator has stagnation planes
- Requires extensive time and effort
- Spatial resolution not very high for mechanical patternator
- Results show that mass flux centers correlate well with surface area centers

**Fully automated plume analysis for quality audit**
Comparison with Conventional methods

- Diffraction based drop sizing methods have large errors (+/- 20%) due to beam wandering
- Shadowgraph based videos do not provide for the analysis of individual plumes
- Phase doppler based methods are time consuming and inaccurate (+/- 10%) for mapping entire sprays
- Mie scattering based imaging not useful
Conclusions

- Extinction based measurements show higher consistency that diffraction or scattering based measurements under real operating conditions.
- Planar extinction tomography has been shown to be the only method available for ranking multiple orifice nozzles or for quality audit purposes.
- The SETscan patternator is the only patternator that provides quantitative information in fuel injectors.