Particle Size and Number Emissions from Dual-Fuel Reactivity Controlled Compression Ignition

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Outline

• Introduction
• Effects of Gasoline SOI
• Effects of Gasoline/Diesel Proportion
• Conclusions
What is Dual-Fuel RCCI?

- **Premixed Combustion**
  - Very Low PM and NO\textsubscript{x} emissions through low local equivalence ratios during combustion

- **In-Cylinder Blending of Higher and Lower Reactivity Fuels**
  - Increased control of ignition (longer premixing possible)
  - Stratification of fuel reactivity and local equivalence ratio for lower rate of combustion
  - Greatly reduced EGR dependence compared to premixed diesel LTC concepts

- **Increased Brake Thermal Efficiency**
  - Through reduced heat transfer losses and optimized combustion phasing
  - Decreased specific fuel consumption
  - Decreased specific CO\textsubscript{2} emissions
Objectives

• Measure particle size and number emissions from heavy-duty dual-fuel RCCI with both fuels injected in-cylinder

• Study effects of in-cylinder gasoline injection timing on exhaust particle emissions (while fixing in-cylinder diesel injection timings)

• Investigate effects of gasoline/diesel proportioning on exhaust particle emissions
Conv. Diesel Particle Size Distribution

Kittelson Model

“The nuclei mode typically contains 1-20% of the particle mass and more than 90% of the particle number.”

Kawai Model

“Hypothetical model for Diesel nano-particle distribution.”
Montajir, Kawai, Goto, Odaka, SAE 2005-01-0187
• Mono-modal shaped size distribution
• Decreased number of larger particles was accompanied by increased number of smaller particles

1.35 bar $P_{int}$

SAE 2010-01-1121
(Benajes, Novella, Arthozoul, Kolodziej)
Premixed Diesel LTC PM - Impingement

- Liquid fuel impingement during earlier injections
- Initially only increased number of larger particles
- Bi-modal size distribution when number of smaller particles increased as well (by 2 orders of magnitude)

Benajes, Garcia-Oliver, Novella, Kolodziej, Fuel, 2011
• Decreased intake O₂ caused a general increase in mono-modal size distributions, though PM mass was similar
• Much fewer particles larger than 100 nm compared to conventional diesel combustion (higher P_{int} than previous slide)
• Diameter of peak number concentration smaller than 60 nm
Test Methodology

- Sweep gasoline injection timing from -300 to -360 °aTDC at each fuel reactivity test condition
- Vary intake temperature to maintain constant CA50
- Vary intake pressure to maintain overall equivalence ratio

<table>
<thead>
<tr>
<th>Gasoline In-Cylinder Injection Timing [°aTDC]</th>
<th>-360, -340, -320, -300</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Diesel In-Cylinder Injection Timing [°aTDC]</td>
<td>-58</td>
</tr>
<tr>
<td>Second Diesel In-Cylinder Injection Timing [°aTDC]</td>
<td>-38</td>
</tr>
<tr>
<td>Gasoline Proportion [%]</td>
<td>65 74 80 84</td>
</tr>
<tr>
<td>Diesel Proportion [%]</td>
<td>35 26 20 16</td>
</tr>
<tr>
<td>Intake Temperature [°aTDC]</td>
<td>27 37 47 57</td>
</tr>
<tr>
<td>Intake Pressure [bar]</td>
<td>1.09 1.1 1.13 1.15</td>
</tr>
<tr>
<td>EGR Rate [%]</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>
RCCI Exhaust Dilution Conditions

- Varied heated primary dilution air ratio
- Fixed ambient-temperature secondary dilution ratio at maximum of Dekati FPS-4000 diluter
- Total dilution ratio (TDR) of 130-135:1 was used for testing
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Effects of Gasoline SOI

- Advanced gasoline injection timing caused slight PM mass increase from -300 to -340°aTDC
- More noticeable increase from -340 to -360°aTDC

- Slight decrease in total particle numbers from -360 to -300°aTDC
- Two-fold higher particle number emissions from lowest gasoline proportion
Effects of Gasoline SOI

-360°aTDC
-340°aTDC
-320°aTDC
-300°aTDC

Mobility Diameter [nm]

\( \frac{dN}{d\log D_p} \) [#/cc]

65% Gas : 35% Diesel

74% Gas : 26% Diesel

80% Gas : 20% Diesel

84% Gas : 16% Diesel
Conclusions (Gasoline SOI)

- Advancing gasoline SOI increased PM mass and number emissions for all gasoline cases, especially from -340 to -360°aTDC.
- Change from -340 to -360°aTDC was characterized by a sharp increase in accumulation mode and simultaneous decrease in nucleation mode (similar to diesel LTC SOI study).
- Decreased number of larger particles with increased number of smaller particles produced less change in total particle numbers than in PM mass.
- Further work is needed to determine if decreased number of larger particles (and PM mass) was due to decreased formation or increased oxidation effects.
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Effects of Gasoline Proportion

- Increased gasoline proportion, decreased PM mass
- Gasoline -360°aTDC SOI had higher PM for all fuel blends
- Increased gasoline proportion also decreased total particle numbers
Conclusions (Fuels)

- Increasing gasoline proportion caused a simultaneous decrease in numbers of larger and smaller sized particles (similar to diesel LTC intake O₂ study)
- Further work needed to understand driver of the simultaneous decrease in both the smaller and larger sized particles with increased gasoline proportion
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Conclusions (General)

- PM mass emissions were reduced below the Smokemeter minimum detection limit (<0.05FSN) in lowest engine operating conditions.
- Particle number emissions were reduced to a similar order of magnitude as the “best” premixed diesel LTC cases (12-13% Intake O₂ with 1.6 bar P_{int}).

**Although RCCI is a form of premixed combustion, its particle size distributions were bi-modal (unlike the mono-modal size distributions typical of premixed diesel LTC).**
Thank you for your attention.
Questions?

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