A Comparison of Combustion and Emissions of Diesel Fuels and Oxygenated Fuels in a Modern DI Diesel Engine

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Outline

• Background
• Experimental Method
• Experimental Results
• Summary & Conclusions

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Canola-based FAMEs (CME) has relatively good cold flow properties & oxidative stability.

DBS further improves the cold flow properties of CME.

To stay within the 40 CN U.S requirement, DBS content in CME must be limited to 40%.
Single-Cylinder Study Objectives

Study the influence of selected oxygenated fuels on combustion and emissions in a modern diesel engine

– Conventional Combustion
– Low Temperature Combustion (LTC)
Outline

- Background
- Experimental Method
- Experimental Results
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## Fuels Tested

<table>
<thead>
<tr>
<th></th>
<th>Mineral Diesel Fuels (Control group)</th>
<th>Oxygenated Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>720</td>
<td>727</td>
</tr>
<tr>
<td>Cetane No.</td>
<td>45.6</td>
<td>41.8</td>
</tr>
<tr>
<td>NHV (MJ/kg)</td>
<td>42.9</td>
<td>42.4</td>
</tr>
<tr>
<td>H:C ratio</td>
<td>1.81</td>
<td>1.775</td>
</tr>
<tr>
<td>O:C ratio</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aromatics</td>
<td>28.6%</td>
<td>32.4%</td>
</tr>
</tbody>
</table>

*A low aromatic diesel fuel included in the study (97.7% saturates)
Test Conditions

- A single-cylinder version of the production 6.7L V8 PowerStroke®.
- Evaluated over the entire engine map.
Test Procedure

Testing attempted to mimic diesel engine controls

- Calibration settings are based on engine speed and fuel quantity
  - Fuel pressure
  - Pilot fuel quantity

- Established base calibration settings using 720 fuel (46 CN)
- Identical settings for all fuels:

<table>
<thead>
<tr>
<th></th>
<th>Rail pressure</th>
<th>Main quantity</th>
<th>Pilot quantity</th>
<th>Pilot SOI</th>
<th>Main timing</th>
<th>EGR rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td>720 calibration setting</td>
<td></td>
<td></td>
<td>720 SOI</td>
<td>Sweep</td>
</tr>
<tr>
<td>LTC</td>
<td>720 cal. settings</td>
<td>No pilot</td>
<td></td>
<td></td>
<td>720 SOC</td>
<td>Sweep</td>
</tr>
</tbody>
</table>

- Select conditions also tested with constant injected fuel energy by adjusting the quantity of each fuel pulse (adjusted for fuel NHV).
Outline

• Background
• Experimental Method
• Experimental Results
  – Emissions
  – Combustion noise (not presented)
  – BSFC & Efficiency (not presented)
• Summary & Conclusions
NOx and Oxygenated Fuels

- NOx emissions appear to be primarily a function of intake oxygen concentration for both fuels (independent of fuel oxygen content).
- At the same intake O₂, no statistical difference in NOx was observed with oxygenated fuels.
- EGR is typically controlled based on an EGR rate or air mass flow.
- Fuel O increases the total intake O₂ for a given EGR rate – NOx increases.
Example Control Scenario

- Commanded fuel quantity will increase to adjust for lower fuel energy.
- As commanded fuel quantity increases, typically EGR rate decreases, boost and injection pressure increase.
- Leads to a further increase in NOx emissions.

1 – higher intake O2

2 – lower EGR rate, higher boost pressure, higher injection pressure
- Large PM reductions with both oxygenated fuels
- Mechanism #1: PM reduction is due to displacement of aromatic
  - A relatively small PM reduction with low aromatic fuel (668)
  - PM reduction with 668 was not statistically significant
- Mechanism #2: PM reduction is the result of fuel oxygen
  - PM reduction is consistent with fuel oxygenation
  - Consistent with estimated oxygen equivalence ratio at the lift-off length
Hydrocarbon Emissions

Conventional Combustion
• Higher HC emissions observed with the 60-40 blend.
• Pilot heat release was weak with the 60-40 blend due to low energy content and low cetane number.

LTC
• Results track with cetane number rather than oxygenation
  - 668 & CME: low HC
  - 727 & 60-40: high HC
• True also of combustion noise (not shown)
HC Emissions with Compensation

- Equivalent HC emissions with the 60-40 blend vs. the base fuel once injected quantity was adjusted for fuel energy content

- Adjusting quantity reduced HC in LTC for both oxygenated fuels
  - Increased load
  - Shorter ignition dwell
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# Effect of Oxygenation - Summary

<table>
<thead>
<tr>
<th></th>
<th>Conventional Combustion</th>
<th>Low Temperature Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>Oxygenation had no effect(^1)</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>Decreased significantly w/ fuel oxygen</td>
<td></td>
</tr>
<tr>
<td>HC</td>
<td>Same as diesel(^2)</td>
<td>Function of cetane(^3)</td>
</tr>
<tr>
<td>Noise</td>
<td>Same as diesel(^2)</td>
<td>Function of cetane</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td></td>
<td>Oxygenation had no effect(^2)</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>Degraded due to lower NHV(^4)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Maintaining calibration settings, including intake O\(_2\).

\(^2\) Adjusting injected fuel quantity for fuel energy content.

\(^3\) Lower HC when injected fuel quantity adjusted for fuel energy content.

\(^4\) A function of fuel energy density.
Thank you!
<table>
<thead>
<tr>
<th>Type</th>
<th>Single-cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle</td>
<td>4-stroke</td>
</tr>
<tr>
<td>Valves per cylinder</td>
<td>4</td>
</tr>
<tr>
<td>Bore</td>
<td>99 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>108 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>0.83 L</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>16.2:1</td>
</tr>
<tr>
<td>Maximum Rail Pressure</td>
<td>2000 bar</td>
</tr>
<tr>
<td>Combustion system design</td>
<td>Chamfered</td>
</tr>
</tbody>
</table>

* Engine & combustion system specifications matched the production 6.7L PowerStroke®
• Differences in combustion noise correlate with cetane number of the test fuel in both conventional combustion and LTC.
• Compensation for NHV reduces slightly difference from 720 fuel.

<table>
<thead>
<tr>
<th></th>
<th>High Cetane</th>
<th>Low Cetane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>668</td>
<td>CME</td>
</tr>
<tr>
<td></td>
<td>727</td>
<td>60-40</td>
</tr>
<tr>
<td>CDC</td>
<td>Lower</td>
<td>Similar</td>
</tr>
<tr>
<td>LTC</td>
<td>Similar</td>
<td>Lower</td>
</tr>
</tbody>
</table>
BSFC & Thermal Efficiency

- Higher BSFC with oxygenated fuels
  - Lower NHV
  - Lower BMEP

- Thermal efficiency of CME was comparable to the diesel fuels

- Lower thermal efficiency with the 60-40 blend without fuel quantity adjustment – later combustion phasing

- Similar thermal efficiency for all fuels when injection quantity was adjusted for energy content
It is speculated that NOx increase found in the literature may be due to

- An increase in intake $O_2$ with fuel oxygen content when EGR rate or air mass flow are controlled
- Reduced EGR, increased boost and increased injection pressure when the commanded fueling injection is increased to meet torque demand with oxygenated fuels (lower energy content)
- When the intake $O_2$ and engine calibration are the controlled to the same value, oxygenated fuels do not appear to have a negative impact on NOx emissions in a modern diesel engine