The Influence of Fuel Cetane Number on Catalyst Light-Off Operation in a Modern Diesel Engine

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Diesel Combustion System Technical Expert
## Light-Duty Vehicles (Fleet Average)

<table>
<thead>
<tr>
<th></th>
<th>NOx [g/mi]</th>
<th>NMOG [g/mi]</th>
<th>NOx + NMOG [g/mi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 2, Bin 5</td>
<td>0.07</td>
<td>0.09</td>
<td>0.160</td>
</tr>
<tr>
<td>Tier 3, 2025</td>
<td></td>
<td></td>
<td>0.030</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
<td>-81%</td>
</tr>
</tbody>
</table>

## Heavy-Duty Pickups & Vans

<table>
<thead>
<tr>
<th></th>
<th>Class 2b</th>
<th>Class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx [g/mi]</td>
<td>NMOG [g/mi]</td>
</tr>
<tr>
<td>Tier 2</td>
<td>0.2</td>
<td>0.143</td>
</tr>
<tr>
<td>Tier 3</td>
<td></td>
<td>0.170</td>
</tr>
<tr>
<td>Difference</td>
<td>-50%</td>
<td></td>
</tr>
</tbody>
</table>

Future emissions standards require solutions that deliver substantial reductions in NOx + NMOG.
Increased exhaust temperature and enthalpy for faster light-off and lower emissions are needed during catalyst light-off operation.

- The majority of tailpipe emissions are emitted before the aftertreatment reaches operating temperature.
- Most manufacturers operate in a catalyst light-off mode during that time to provide exhaust heat to sufficiently low emissions.

*HC acts as a surrogate for NMOG.
Engine Operation for Catalyst Light-Off

- Typical catalyst light-off strategy (retard combustion)
  - Retard SOIs
  - Shift fuel to post injections

- Temperature increases as combustion is retarded
  - Lower efficiency – shifting energy to exhaust
  - Increase fuel quantity
  - Late phasing degrades stability
    - Higher HC emissions

Poor ignition and combustion stability of late fuel injections can lead to excessive HC emissions.
A tradeoff exists between exhaust temperature/enthalpy and emissions. Need to improve ignition and combustion stability of late fuel injections.
Cetane Number: a measure of the ignition quality of a diesel fuel.

Minimum CN
EU: 48CN
US: 40CN
Δ=8CN

Average CN
EU: 54CN
US: 45CN
Δ=9CN

Does the relatively low cetane number with US fuel influence the ability to generate exhaust temperature and enthalpy while controlling emissions?
Tested two fuels with a cetane number difference similar to the gap between United States & European diesel fuel.

<table>
<thead>
<tr>
<th></th>
<th>US Certification Fuel</th>
<th>High Cetane Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane Number</td>
<td>46</td>
<td>53</td>
</tr>
<tr>
<td>Lower Heating Value [MJ/kg]</td>
<td>42.9</td>
<td>42.9</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>842</td>
<td>837</td>
</tr>
<tr>
<td>H/C ratio</td>
<td>1.82</td>
<td>1.97</td>
</tr>
<tr>
<td>O/C ratio</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aromatics [wt%]</td>
<td>29.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Kinematic Viscosity [cSt]</td>
<td>2.9</td>
<td>2.3</td>
</tr>
<tr>
<td>T90 [°C]</td>
<td>307</td>
<td>334</td>
</tr>
</tbody>
</table>
• Single-cylinder version of the 6.7L PowerStroke®

• Four test conditions
  – Two speed-load points to represent first 200s of FTP
  – 20° and 90°C coolant and oil

• 60-point experiment at each test condition to cover calibration space
  – Injection pressure
  – Injection timings
  – Injection quantities
  – EGR rate
Vehicle Populations to Consider in Fuels Studies

2007-2010

- Legacy Fleet
  - Older vehicles
  - Fixed engine calibration
  - Catalyst light-off calibration

- Fleet
  - Modern vehicles
  - Fixed engine calibration
  - Catalyst light-off calibration

Bulk of cetane effects studies

Present

- Future Fleet
  - Fixed engine calibration
  - Catalyst light-off calibration

Study focus – cetane effect on catalyst light-off operation
• A-B comparison at production calibration

• Pairwise statistical comparison across multiple calibrations, isolating fuel difference

• Comparison at optimum calibrations for each fuel
  – Use experimental data to optimize calibration for each fuel
  – Compare optimums
Statistical comparison across pairwise data (calibrations) isolating difference between two fuels

**Example:**

<table>
<thead>
<tr>
<th>Example</th>
<th>Exhaust Temperature</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuel #1</td>
<td>Fuel #2</td>
<td>Difference</td>
</tr>
<tr>
<td>Calibration 1</td>
<td>$X_1$</td>
<td>$Y_1$</td>
<td>$X_1 - Y_1$</td>
</tr>
<tr>
<td>Calibration 2</td>
<td>$X_2$</td>
<td>$Y_2$</td>
<td>$X_2 - Y_2$</td>
</tr>
<tr>
<td>Calibration 3</td>
<td>$X_3$</td>
<td>$Y_3$</td>
<td>$X_3 - Y_3$</td>
</tr>
<tr>
<td>Calibration 4</td>
<td>$X_4$</td>
<td>$Y_4$</td>
<td>$X_4 - Y_4$</td>
</tr>
<tr>
<td>Calibration 60</td>
<td>$X_{60}$</td>
<td>$Y_{60}$</td>
<td>$X_{60} - Y_{60}$</td>
</tr>
</tbody>
</table>

**Null hypothesis:** fuels have no effect

- 0 inside CI = fuel has no effect (verify null hypothesis)
- 0 outside CI = fuel has an effect
Effect on Legacy Fleet in a Catalyst Light-Off Mode

Comparison across identical calibrations (analysis of all data)
- Little/no difference in exhaust T & H, noise, smoke
- Higher NOx, but lower NOx + HC

Analysis of data from all 4 points together

Increased cetane would have minimal impact on legacy fleet A/T function, but may reduce NOx + HC during catalyst light-off operation.
Optimize calibration for the fuel
- 30% higher exhaust temperature and enthalpy for faster cast light-off
- Higher NOx, but lower NOx+HC and smoke

Potential to more quickly light-off catalysts while controlling emissions with higher cetane fuel, thus reducing TP emissions.
Heat Release Analysis

1200 rpm, 8% load, 90°C

**Heat Release Rate**

- Fed Cert Fuel @ Base Cal
- High Cetane @ Optimized Cal.

**Mass Burn Fraction**

Higher cetane fuel enabled significantly later combustion while controlling emissions.
This study suggests that:
- increasing cetane would have minimal impact on catalyst light-off and may slightly reduce tailpipe emissions in legacy vehicles.
- the relatively low cetane fuel in the US may limit the ability to light-off catalysts while controlling for future emissions standards.
- further study is warranted.

To fully understand the effect of changing fuels specifications, fuels testing should include:
- evaluation with production calibrations to define effects on today’s vehicles.
- optimization of the calibration for the new fuel to estimate the impact on tomorrow’s vehicles.
Ford is Committed to:

Cooperation and collaboration to find high volume solutions for today’s and tomorrow’s challenges