Diesel Fuel Sulfur Effects on the Performance of Lean NO\textsubscript{x} Catalysts

Shouxian Ren

International Truck and Engine Corporation
Objective:

- Evaluate the effects of diesel fuel sulfur on the performance of low temperature and high temperature Lean-NO$_x$ Catalysts.

- Evaluate the effects of up to 250 hours of aging on the performance of the Lean-NO$_x$ Catalysts with different fuel sulfur contents.
# DESCE Lean-NOx Catalyst Evaluation Program

## DESCE Lean-NOx Catalysts

<table>
<thead>
<tr>
<th>Catalyst Type</th>
<th>Catalyst Formulation</th>
<th>Substrate Size (cm)</th>
<th>Number of Substrates</th>
<th>Volume (liters)</th>
<th>Cell Density (cpsi)</th>
<th>Converter Size (cm)</th>
<th>Space Velocity (hr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-temperature</td>
<td>Base metal/ Zeolite</td>
<td>26.7 x 15.2</td>
<td>1</td>
<td>8.5</td>
<td>400</td>
<td>27.3 x 51.4</td>
<td>41,900 – 81,000</td>
</tr>
<tr>
<td>Low-temperature</td>
<td>Precious metal</td>
<td>17.8 x 12.7</td>
<td>2</td>
<td>6.4</td>
<td>400</td>
<td>19.1 x 55.9</td>
<td>15,100 – 63,600</td>
</tr>
</tbody>
</table>

## DESCE Diesel Engines

<table>
<thead>
<tr>
<th>Engine</th>
<th>Displacement (L)</th>
<th>Type</th>
<th>Peak kW @ rpm</th>
<th>Peak Torque (Nm @ rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navistar T444E</td>
<td>7.3</td>
<td>V8</td>
<td>157 (210 hp) @ 2,300</td>
<td>705 (520 ft-lb) @ 1,500</td>
</tr>
<tr>
<td>Cummins ISM370</td>
<td>10.8</td>
<td>I6</td>
<td>276 (370 hp) @ 1,800</td>
<td>1,830 (1,350 ft-lb) @ 1,200</td>
</tr>
</tbody>
</table>

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Steady State Test Modes for Lean-NO\textsubscript{x} Catalysts

**LT**
Lean-NO\textsubscript{x} catalyst

**HT**
Lean-NO\textsubscript{x} catalyst

**4 Nav-9 Modes**

<table>
<thead>
<tr>
<th>NAV-9 Mode</th>
<th>NO\textsubscript{x} (g/bhp-hr)</th>
<th>HC/NO\textsubscript{x} Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.40</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>5.99</td>
<td>12.5</td>
</tr>
<tr>
<td>7</td>
<td>4.35</td>
<td>14.4</td>
</tr>
<tr>
<td>9</td>
<td>3.20</td>
<td>3.9</td>
</tr>
</tbody>
</table>

**4 OICA Modes**

<table>
<thead>
<tr>
<th>OICA-13 Mode</th>
<th>NO\textsubscript{x} (g/bhp-hr)</th>
<th>HC/NO\textsubscript{x} Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>6.53</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>6.37</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>6.12</td>
<td>2.6</td>
</tr>
<tr>
<td>2</td>
<td>6.09</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Effect of Diesel Fuel Sulfur on NOx Reduction with DECSE Lean-NOx Catalysts
Temperature Windows for DECSE Lean-NO\textsubscript{x} Catalysts
(Phillips 3 ppm Sulfur Fuel)

Navistar T444E Engine
(Selected St. St. Modes from NAV-9 modes)

Low T Lean-NO\textsubscript{x} Catalyst (SV: 15.1K - 63.6K hr\textsuperscript{-1})

Cummins ISM 370 Engine
(Selected St. St. Modes from OICA-13 modes)

High T Lean-NO\textsubscript{x} Catalyst (SV: 41.9K - 81.0K hr\textsuperscript{-1})
NO$_x$ Reduction across Four NAV-9 Modes
(Fresh LT Lean-NO$_x$ Catalyst, Navistar T444E Engine)

Graph showing the NO$_x$ reduction (%) across different catalyst inlet temperatures (C) for various secondary fueling consumption modes.

- Phillips 3 ppm Sulfur
- Phillips 30 ppm Sulfur
- Phillips 150 ppm Sulfur
- Phillips 350 ppm Sulfur

Secondary Fueling Consumption

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NO\textsubscript{x} Reduction across Four OICA-13 Modes
(Fresh HT Lean-NO\textsubscript{x} Catalyst, Cummins ISM Engine)

- 3 ppmS NO\textsubscript{x} Reduction
- 30 ppmS NO\textsubscript{x} Reduction
- 150 ppmS NO\textsubscript{x} Reduction
- 350 ppmS NO\textsubscript{x} Reduction
- Secondary Fueling Consumption

Catalyst Inlet Temperature (C)

NO\textsubscript{x} Reduction (%)
Effect of Catalyst Aging on $\text{NO}_x$ reduction with LT Lean-$\text{NO}_x$ Catalyst
(Navistar T444E Engine, Two Modes of NAV-9 Cycle)

Mode 3 of NAV-9 Cycle

Mode 7 of NAV-9 Cycle

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Effect of Catalyst Aging on NO\textsubscript{x} reduction with HT Lean-NO\textsubscript{x} Catalyst
(Cummins ISM Engine, Two Modes of OICA-13 Cycle)

Mode 2 of OICA-13 Cycle

Mode 10 of OICA-13 Cycle
Effect of Diesel Fuel Sulfur on By-product Formation with DECSE Lean-NOx Catalysts
By-Product Formation w/ Fresh LT Lean-NO$_x$ Catalyst
(NAVISTAR T444E Engine, In-exhaust Secondary Fuel Injection)
By-Product Formation w/ Fresh HT Lean-NO\textsubscript{x} Catalyst
(Cummins ISM Engine, In-exhaust Secondary Fuel Injection)
Catalyst Aging Effect on HC Emission with Lean-NOx Catalysts
(In-exhaust Secondary Fuel Injection)

**HC (NAV-9, Mode 3)**
LT Catalyst, Navistar T444E Engine

**HC (OICA-13, Mode 2)**
HT Catalyst, Cummins ISM Engine

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A comparison of $\text{SO}_4$ emissions between converter-out and engine-out with the fresh LT Lean-$\text{NO}_x$ catalyst

Navistar T444E engine, NAV-9 4-mode composite

Navistar T444E engine, NAV-9 mode 9

$T_{in} = 405 \text{ deg C}$
A comparison of SO$_4$ emissions between converter-out and engine-out with the fresh HT Lean-NO$_x$ catalyst

**Cummins ISM engine, OICA 4-mode composite**

**Cummins ISM engine, OICA mode 2**
PM Emission from Lean-NO\textsubscript{x} Catalysts at High Temperature Modes

PM NAV-9, Mode 9
(Navistar T444E Engine)

PM OICA-13, Mode 2
(Cummins ISM Engine)

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Catalyst Aging Effect on Particulate Emission with LT Lean-NOx Catalyst
(Navistar T444E Engine, In-Exhaust Secondary Fuel Injection)
Conclusions:

- Diesel fuel sulfur has no effect on NOx reduction with fresh DECSE Lean-NOx catalysts. Apparently, diesel sulfur content has no effect on NOx reduction during 250 hours of catalyst aging.

- Using 150 and 350ppm sulfur fuels, HC slippage obviously increased with fresh LT Lean-NOx catalyst. With different sulfur contents, great amount of HC and CO slippage were always observed when applying HT Lean-NOx catalyst. Additionally, HC slippage increased with aging time of HT Lean-NOx catalyst.

- Both LT and HT Lean-NOx catalysts showed the capability of making sulfate (SO$_4^{2-}$) at higher temperatures. Significant sulfate formation was observed with 150 and 350ppm sulfur fuels.

- With 350ppm sulfur fuel, huge sulfate (PM) formation was observed during the catalyst aging (up to 400 hours) with LT Lean-NOx catalyst. No significant change of sulfate formation was observed after 50 hour aging.
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- DECSE Data Management Team
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