Diesel Oxidation Catalyst (DOC) System for PM Control

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Presentation Outlines

• Background
  * Social requirements in Japan
  * Importance to develop robust PM control technology for in use diesels

• Experimental Procedure

• Test Results
  1. Impact of DOC on PM Emission (work with Kawasaki)
  2. Impact of DOC on Unregulated Hydrocarbons (work with TMG)
  3. Newly Developed DOC + CSF (Catalysed Soot Filter) Using Ceramic Foam

• Conclusions
Comparison of Diesel Emission Control Technologies

<table>
<thead>
<tr>
<th>Emission Reduction Capability</th>
<th>CO</th>
<th>THC</th>
<th>PM</th>
<th>NOx</th>
<th>S tolerance</th>
<th>Practical possibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Fuel Additive + DPF</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Lean NOx catalyst</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>NOx trap</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CR-DPF (CRT™)</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>SCR</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>CRT + SCR (SCRT™)</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

+++ : very good, + : good, - : not suitable

Legislation for In-Use HDD Enforced by Tokyo Metropolitan Government

-60% -70%
1994 standard
Tokyo Local regulation value for in-use diesels
30%
Emission standard for newly registered vehicle
Past and Future NOx and PM Legislations

NOx/PM ratio on in use diesels in Japan are around 10 to 20.

How to Improve? -DOC + CSF System Principle-
Temperatures Conditions During Low Temperature Cycle

![Temperature Graph]

Ref: R. Allansson et al., SAE Paper 2002-01-0428

Low Temperature Cycle (40 hrs) Performance in MK1 Fuel

![Back Pressure Graph]

Ref: R. Allansson et al., SAE Paper 2002-01-0428
**Experimental Conditions**

*Less than 50 ppm S fuel was used for all test.
Test 1: Collaboration work with Kawasaki-city.
Test 2: Collaboration work with Tokyo metropolitan Research Institute for Environmental Protection.

<table>
<thead>
<tr>
<th>Vehicle/Engine</th>
<th>DOC</th>
<th>CSF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle type</strong></td>
<td><strong>Engine size (L)</strong></td>
<td><strong>Size (mm)</strong></td>
</tr>
<tr>
<td><strong>Test 1</strong></td>
<td>Garbage truck</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td>City bus</td>
<td>10</td>
</tr>
<tr>
<td><strong>Test 3</strong></td>
<td>Engine Bench</td>
<td>13</td>
</tr>
</tbody>
</table>

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**Specifications of Tokyo Metropolitan City Bus**

**Vehicle Specifications**

<table>
<thead>
<tr>
<th>Engine Maker</th>
<th>Hino</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Type</td>
<td>M10U (DI, 6 cylinders)</td>
</tr>
<tr>
<td>Engine Displacement</td>
<td>9.88 L</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>230 PS / 2500 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>70 kgm / 1500 rpm</td>
</tr>
<tr>
<td>Registration</td>
<td>Feb.,1993 (HT2MLA47043)</td>
</tr>
</tbody>
</table>
Tokyo City Mode 2, 5, 8 and 10

Tokyo City Mode #2
Average speed: 8.4 km/h

Tokyo City Mode #5
Average speed: 18.0 km/h

Tokyo City Mode #8
Average speed: 28.5 km/h

Tokyo City Mode #10
Average speed: 44.4 km/h

Temperature Frequency on Tokyo City Modes

Tokyo City Mode #2
>300°C: 5%

Tokyo City Mode #5
>300°C: 19%

Tokyo City Mode #8
>300°C: 32%

Tokyo City Mode #10
>300°C: 74%
Engine Map Points with Weighting Factor on Japanese D13 Mode

Test Results
- PM reduction Efficiency over DOC -
PM Reduction Efficiencies on DOC over Kanagawa-Prefecture Modes

Conventional DOC testing on Garbage Truck (5L engine)

Emitted Carbonaceous Matter over Kanagawa-Prefecture Modes

Garbage Truck (5L engine)
Emitted PAHs and Benzo-(a)-Pylene over Kanagawa-Prefecture Modes

- Engine base
- With catalyst
- 78% reduction
- 63% reduction
- 61% reduction
- 77% reduction

Emitted Benzo-(a)-pylene / ug/km

Low speed mode (Average : 12.65 km)
High speed mode (Average : 24.1 km)

Unregulated Hydrocarbons Reduction Efficiencies over Tokyo City Modes

* City Bus test : 10L engine

Formaldehyde
Acetaldehyde
1, 3-Butadiene
Benzene
Vehicle Test Summary

1. DOC installed on garbage truck can reduce more than 40% PM. The reduction efficiency depends upon the vehicle driving condition.

2. DOC mainly reduced organic carbons (SOF) into PM and no effective function to reduce elementary carbons (Soot).

3. DOC effectively reduced many kinds of unregulated hydrocarbons at various driving condition.

- PM reduction Efficiency over DOC + CSF -
How to Improve?

[PM combustion rate] ≥ [PM accumulation rate]

- Increase NOx concentration
  (Out of control)
- Improve temperature condition
  (Dual skin tube)
- Catalyzed filter
  (Pt base catalyst)
- Reduce PM emissions
  (Out of control)
- Low efficiency filter
  (Wire mesh, Foam type)

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System Concept of DOC+CSF Using Foam Filter

1. Use NO many times in the unit
   Frame by frame reaction of NO2 with C
2. Larger geometrical surface area (GSA) than wall-through type
   DPF, and can increase number of contact point with PM

<table>
<thead>
<tr>
<th>Foam filter</th>
<th>Wall-through filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>#30</td>
<td>12/200</td>
</tr>
<tr>
<td>GSA(cm²/cm³)</td>
<td>43</td>
</tr>
</tbody>
</table>

3. Acceptable backpressure level as CSF
NO2 Reaction with C in Coated Foam Filter

* Frame by Frame Reaction of NO2 with C

Outward of Cordielite Ceramic Foams
**Plate Stack and Cylindrical Design**

<table>
<thead>
<tr>
<th></th>
<th>Plate stack Type</th>
<th>Cylindrical Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>High</td>
<td>Low(in parallel)/High(in series)</td>
</tr>
<tr>
<td>D. Pressure</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Canning (Mechanical strength)</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
</tbody>
</table>

**PM Emissions over D13 mode**

![Graph showing PM emissions over D13 mode](image)
PM Emissions over Tokyo City Mode #5
- Blow-Off Effect while Transient Test -

PM mass over TMG mode#5 / mg

<table>
<thead>
<tr>
<th>Engine out</th>
<th>With DOC + Foam filter (OD240 X ID90, 20 cpi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soot</td>
<td>SOF</td>
</tr>
<tr>
<td>-43%</td>
<td></td>
</tr>
</tbody>
</table>

PM Emissions over D13 Mode and Tokyo City Mode#5

PM Emission / g/kwh

<table>
<thead>
<tr>
<th>Engine out A: OD240 X ID90</th>
<th>Engine out B: OD240 X ID90</th>
</tr>
</thead>
<tbody>
<tr>
<td>-37%</td>
<td>-44%</td>
</tr>
<tr>
<td>-45%</td>
<td>-56%</td>
</tr>
</tbody>
</table>
Conclusions

1. DOC can reduce part of the PM, especially organic carbons. The reduction efficiency depends upon the SOF content and temperature at driving condition.

2. DOC effectively reduced unregulated hydrocarbons emitting from diesel engines. This is additional advantage to use DOC, not only for reducing PM mass.

3. System performance of newly developed DOC + catalyzed foam filter was demonstrated and showed promising results.
   * On this system, around 50% PM reduction efficiency was confirmed on both steady state mode and transient modes.
   * This system enable to cover the specific PM reduction target in between DOC and conventional wall-through DPF.

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Thank you!