Evaluation of the CanmetENERGY Prototype Catalyzed Diesel Particulate Filter: Determination of the Balance Point Temperature

L. Nossova¹, G. Caravaggio¹, B. Rubeli², D. Young²

¹CanmetENERGY – Ottawa
²CanmetMINING – Ottawa

Current Diesel PM Control

- Filtration of particulate matter (PM): Diesel particulate filter (DPF)
- Active Regeneration
  - Reduces DPF life and increases fuel consumption
- Passive Regeneration: Catalyzed DPF
  - commercial NO₂-based technologies
    - Continuously Regenerating Trap (CRT)
    - Catalyzed CRT (CCRT)
    - Catalyzed Soot Filter (CSF)
- Limitations of NO₂-based technologies:
  - Pt catalyst – expensive and sensitive to sulfur
  - High concentration of NO (high NO/PM ratio)
- Challenges for catalyst development:
  - Non PGM catalyst with high sulfur resistance and durability
  - Lower light-off temperatures for PM/soot oxidation
  - High activity without NO/NO₂
Catalyst Development

Objective: Development of a low cost catalyst to reduce PM emissions from heavy duty diesel vehicles at temperatures of diesel exhaust

- Optimization of preparation methods
- Optimization of catalyst formulation
- Catalyst Characterization (TPO, BET, XRD)
- Catalyst for PM oxidation
- Engine test of a Prototype CDPF
- Fabrication of a prototype CDPF
- Catalyst evaluation: bench scale, simulated diesel exhaust
- Catalyst large batch synthesis
- Fabrication of a prototype CDPF
- Engine test of a Prototype CDPF
- Catalyst large batch synthesis

Catalytic Testing Unit (CTU)

- **Sample:**
  Catalyst : Carbon Black = 30:1, tight contact, 500 mg, 250 mg cordierite
- **Feed composition:**
  10 vol% O₂, 5 vol% H₂O, 500 ppm NO (10 ppm SO₂ optional)
- **GHSV:** 60k-80k h⁻¹
- **Temperature:** 150°C-600°C @ 3°C/min

Sieved catalyst particles (80-120 mesh) mixed with carbon particles in tight mode
### CTU Test Results: Simulated Diesel Exhaust

500 mg mixture diluted with 250 mg of cordierite, 3°C/min from 150 to 600°C,

- $T_{\text{max}}$ is selected as an activity indicator
- High activity for carbon oxidation and sulfur resistance

### CTU Test Results: Hydrothermal Stability

- Aging protocol: 10 vol% O$_2$, 5 vol% H$_2$O, 750°C, 15 h
- Testing feed gas: 10 vol% O$_2$, 5 vol% H$_2$O, 500 ppm NO
CanmetENERGY Prototype CDPF

- Unit batches: ~100 g
- Large batch catalyst: 1.3 Kg
- Activity of small and final batches were confirmed by CTU testing
- Cordierite core (400 cps)
- Stainless steel can
- 12.5 L
- CanmetENERGY catalyst
- Catalyst loading: 38 g/L
- Manufactured by DCL International Inc.

Engine Test of CDPFs

Experimental Approach

- CanmetMINING accredited testing laboratory (ISO/IEC 17025)
- Comparison of the CanmetENERGY CDPF with the commercial base metal-palladium CPDF “Cattrap” produced by CDTi for mining operations
- Split flow and no DOC
- Low sulfur mining diesel fuel
- Pre-loading of diesel particulate on each CDPF to a predetermined level
- Determination of Balance Point Temperature (BPT) of each CDPF according to DECSE program

Engine Specification Data

<table>
<thead>
<tr>
<th>Make</th>
<th>Detroit Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>6063-WK32, Series 60</td>
</tr>
<tr>
<td>Serial number</td>
<td>06R0442911</td>
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<tr>
<td>Displacement</td>
<td>11.1 Liter</td>
</tr>
<tr>
<td>Rated power</td>
<td>242 kW @ 2100 rpm</td>
</tr>
<tr>
<td>Peak torque</td>
<td>1539 N.m @1200 rpm</td>
</tr>
<tr>
<td>Intermediate speed</td>
<td>1260 rpm</td>
</tr>
<tr>
<td>Aspiration</td>
<td>Turbocharged, charged air cooled</td>
</tr>
<tr>
<td>Fuel system</td>
<td>DI, Electronically controlled fuel injection</td>
</tr>
<tr>
<td>Max exhaust backpressure</td>
<td>10.1 kPa</td>
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<tr>
<td>Low idle speed</td>
<td>600 rpm</td>
</tr>
<tr>
<td>High idle speed</td>
<td>2225 rpm</td>
</tr>
</tbody>
</table>

CanmetMINING Engine Test Unit

CanmetENERGY CDPF set up

"Cattrap" CDPF set up
Test Procedure

Pre-loading of diesel particulate matter (PM)
- Engine speed of 2100 rpm and 10% load
- Temperature below the catalyst light-off temperature
- Duration about 30 h
- CDPF weight before and after loading

BPT determination
- Progressive engine load at 10 min intervals
- Stepwise change of CDPF inlet temperature (T)
- CDPF pressure drop (ΔP) recording
- Relationship between ΔP and T to determine ΔP=0

Results: PM Pre-loading

CanmetENERGY CDPF
- Initial delta ΔP: 2.1 kPa
- Final delta ΔP: 10.4 kPa
- Initial DPF mass: 13.86336 kg
- Estimated mass: 81.2 g
- Loading rate: 0.31 kPa/hour
- Average DPF Inlet Temperature: 205°C
- Initial delta ΔP: 2.1 kPa
- Final delta ΔP: 10.4 kPa
- Initial DPF mass: 13.94456 kg
- Estimated mass: 81.2 g
- Loading rate: 0.31 kPa/hour
- Average DPF Inlet Temperature: 205°C

“Cattrap” CDPF
- Initial delta ΔP: 3.5 kPa
- Final delta ΔP: 10.4 kPa
- Initial DPF mass: 19.7702 kg
- Estimated mass: 104.5 g
- Loading rate: 0.21 kPa/hour
- Average DPF Inlet Temperature: 225°C
- Initial delta ΔP: 3.5 kPa
- Final delta ΔP: 10.4 kPa
- Initial DPF mass: 19.8747 kg
- Estimated mass: 104.5 g
- Loading rate: 0.21 kPa/hour
- Average DPF Inlet Temperature: 225°C

y = 0.3124x + 2.1247
y = 0.2129x + 3.2606
• Characteristic pressure pulsations
• \( \Delta P \) increase as a result of CDPF loading
• BPT range indicated by decreasing \( \Delta P \)
• Simple BPT indicated by rapid decreasing \( \Delta P \)

(3) BPT \(-310-348^\circ C\)

(4) Simple BPT \(-349^\circ C\)

Due to pressure pulsations the \( \Delta P \) slope is difficult to model
• BPT range was selected where an obvious decrease in \( \Delta P \) occurred
• Simple BPT was selected near the point where rapid decrease in \( \Delta P \) was observed
Extent of Regeneration by Borescope in CanmetENERGY CDPF

CDPF channel in the fully loaded state

CDPF channel in the partially loaded state

CDPF channel in the fully regenerated state

BPT of “Cattrap” CDPF

ΔP and Inlet Temperature versus Time

(3) BPT ~378–410°C

(4) Simple BPT ~ 454°C
Results: BPT of two tested CDPFs

<table>
<thead>
<tr>
<th>Type of filter</th>
<th>BPT range (°C)</th>
<th>Simple BPT (°C)</th>
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<tbody>
<tr>
<td>CanmetENERGY p-CDPF</td>
<td>310 - 348</td>
<td>349</td>
</tr>
<tr>
<td>Cattrap CDPF</td>
<td>379 - 410</td>
<td>454</td>
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- The CanmetENERGY CDPF demonstrated ability for starting passive regeneration at 310°C
- The characteristic simple BPT and balance point temperature range for the “Cattrap” DPF agrees with the manufacturer’s balance point temperature range of 380 to 420°C

Conclusions

- A highly effective catalyst for soot oxidation was developed
- A prototype catalyzed diesel particulate filter (CanmetENERGY CDPF) with the developed catalyst was manufactured and tested on a diesel engine
- The CanmetENERGY CDPF was found to have a significantly lower balance point than a commercially available base metal – palladium CDPF (“Cattrap”)
- This measured improvement in DPF regeneration performance suggests the potential for the CanmetENERGY CDPF to oxidize PM during normal engine operation (passive regeneration)
**Future work**

- The performance of the CanmetENERGY CDPF could be compared to the conventional platinum-based CRT system
- Long-term stability of the developed CDPF needs to be tested
- Additionally, effectiveness in control of gaseous emissions such as CO, hydrocarbons and NO$_x$ compared to noble metal-based CDPFs needs to be evaluated

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