Enhanced thermal and gas flow performance in a three-way catalytic converter through use of insulation within the ceramic monolith

Timothy Ley,¹ Voislav Blagojevic,¹,² Gregory K. Koyanagi,¹,² Sarry Al-Turk,¹ Robert E. Hayes³ and Stefano Plati¹

¹Vida Holdings Corp, Toronto, ON, Canada; ²Department of Chemistry, York University, Toronto, ON, Canada; ³Department of Chemical and Materials Engineering, University of Alberta, AB, Canada
Multi-Chamber Catalytic Converter (MCCC)

- MCCC inserts an insulation layer within the standard ceramic monolith
- Influences thermal flows between the inner and outer zones of monolith
- Results in better thermal management
- Impacts distribution of exhaust gas across the face of the monolith
OEM Proof of Concept Testing

- Ford Edge Duratec 3.5L testbed
  - **Baseline** (standard Ford part)
    - 900/2.5 CPSI front monolith
    - 400/6.5 CPSI rear monolith
  - **MCCC-1** *(PGM reduction)*
    - 900 CPSI front monolith (5% shorter, -25% PGM)
    - 400 CPSI rear monolith (5% shorter, -25% PGM)
  - **MCCC-2** *(900 CPSI monolith replacement)*
    - 400/6.5 CPSI front monolith (-5% PGM)
    - 400 CPSI rear monolith (5% shorter, -9% PGM)
  - All aged to 100,000 miles, 3 tests per prototype
**OEM Proof-of-Concept Testing**

**FTP NOx Bag Emissions**

<table>
<thead>
<tr>
<th>Emissions (g/mile)</th>
<th>FTP bag 1</th>
<th>FTP bag 2</th>
<th>FTP bag 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCCC-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.04</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>0.08</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>AV</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>MCCC-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.05</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>0.08</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>AV</td>
<td>0.06</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>0.08</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>3</td>
<td>0.09</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>AV</td>
<td>0.08</td>
<td>0.04</td>
<td>0.06</td>
</tr>
</tbody>
</table>
OEM Proof-of-Concept Testing
US06 Emissions Data

- MCCC1: 0.575 NMHC, 4.61 NOx, 6.11 CO/10
- MCCC2: 0.523 NMHC, 4.87 NOx, 6.11 CO/10
- Baseline: 0.591 NMHC, 4.87 NOx, 6.11 CO/10

Emissions (g/mile)
OEM Proof-of-Concept Testing
HwyNOx Emissions Data

Emissions (g/mile)

<table>
<thead>
<tr>
<th></th>
<th>MCCC-1</th>
<th>MCCC-2</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.095</td>
<td>0.041</td>
<td>0.111</td>
</tr>
</tbody>
</table>

OEM Proof-of-Concept Testing
HwyNOx Emissions Data

Emissions (g/mile)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>AV</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCCC-1</td>
<td></td>
<td></td>
<td></td>
<td>0.095</td>
</tr>
<tr>
<td>MCCC-2</td>
<td></td>
<td></td>
<td></td>
<td>0.041</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td>0.111</td>
</tr>
</tbody>
</table>
Emissions Testing Summary

- Ford Edge Duratec 3.5L testbed
  - MCCC-1 (PGM reduction prototype)
    - 5% shorter, -25% PGM
    - Slightly better emissions across the board
  - MCCC-2 (900 CPSI monolith replacement)
    - 400 CPSI front monolith, -6% PGM
    - Slightly higher hydrocarbon and CO emissions
    - Major NOx reduction (-10% FTP, -23% US06, -63% HwyNOx)
Thermal Management Testing

- MCCC design goals:
  - Improve light-off performance within inner zone
  - Improve heat retention within outer zone

- Temperature monitoring carried out within each zone
- 5 thermocouples were inserted into the monolith
- 1 T/C on the centerline (in the inner zone) and 4 T/Cs in the outer zone

T – Thermocouple position
Thermal Management Testing
Inner Zone Temperature Profiles

- 900/400 MCCC-1 exhibits marginally faster light-off
- 400/400 MCCC-2 exhibits superior heat retention
**Thermal Management Testing**

**Outer Zone Temperature Profiles**

- Outer zone of MCCC monolith acts as a heat sink during idle and stop – enhancing heat retention
- Helps overall emissions – particularly NOx

FTP Phase 1 Temperature Monitoring:
Average temperature of 4 thermocouples on the outside of the insulation
Improved Exhaust Gas Distribution

- Effects velocity distribution across monolith face
- Reduces backpressure – improves fuel economy
- Flattens residence time distribution thereby improving catalytic conversion efficiency

**Velocity Magnitude (m/s)**

**Position (cm)**

- **MCCC**
  - $V_{\text{min}} = 2.8$ m/s
  - $V_{\text{max}} = 5.0$ m/s

- **Baseline**
  - $V_{\text{min}} = 2.5$ m/s
  - $V_{\text{max}} = 5.5$ m/s
CFD Modeling Supports Lower Backpressure

- CFD modeling
- Static Pressure
- Fluent 12.1
- Medium Load
MCCC Conclusions

- Enhances thermal characteristics for catalytic converter monoliths
  - Continued emission reduction during idle and stops
- Lower backpressure through better exhaust gas distribution
  - Improved fuel economy
- Uses shorter length monoliths and reduced PGM loadings
  - Cost savings
- Improves emission performance (particularly NOx)
  - 400/400 MCCC emission performance matches standard 900/400
- Cost competitive with current catalytic converter technology
Acknowledgments

• Vida Holdings
  • Sarry Al-Turk
  • Dr. Voislav Blagojevic
  • Stefano Plati (President)

• University of Alberta
  • Lito Rajab
  • Prof. Robert E. Hayes

• York University, Toronto
  • Gregory K. Koyanagi
  • Prof. Diethard K. Bohme

• University of Waterloo
  • Prof. Bill Eppling

• Ford Motor Company
  • Dave Kunitz

• Johnson Matthey Testing
  • Steve Beaver

• Funding
  • Automotive Partnership Canada (APC)