Catalyst Design for Urea-less Passive Ammonia SCR Lean-Burn SIDI Aftertreatment System

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Fuel Efficiency vs. Emission Control

- **Passive Ammonia SCR System**
  - Lean NO$_x$ Trap
    - High PGM Cost
    - Sulfur Poisoning
    - Desulfation Required
  - Conventional TWC
    - Poor NO$_x$ efficiency with DFCO / Lean-Idle
  - Urea-SCR
    - Secondary urea tank with injection system
    - Urea Solution Freezing

- **EXHAUST OXYGEN CONTENT**
PASS - How Does It Work?

Urea-Free SCR System

**DURING RICH:**

\[ \text{NO}_x + H_2/CO \leftrightarrow \text{NH}_3 + \text{CO}_2 \]

Use H₂ and CO to generate NH₃ over TWC and store NH₃ in multiple SCRs

**DURING LEAN:**

\[ \text{NO}_x + \text{NH}_3 \leftrightarrow \text{N}_2 + \text{H}_2\text{O} \]

Use the stored NH₃ for lean NOₓ conversion
NEDC Results from Stratified Charge Application – *Extended Lean Operation*

Dynamometer data based on: European Passenger Car – I4, Manual Transmission

**TWC**
- Front Brick: 0.8 L, 200 g/ft³, 0/200/0
- Rear Brick: 1.2 L, 70 g/ft³, 0/60/10

**SCR**
- 2.0 L, Cu-based

→ Poor NOx conversion over TWC during NEDC

→ TWC produced NH3 with rich operation

**Engine Out NOx**

**Post-TWC NOx**
NEDC Results from Stratified Charge Application – *Extended Lean Operation*

**Post-TWC NO\textsubscript{x}**
- Front Brick: 0.8 L, 200 g/ft\textsuperscript{3}, 0/200/0
- Rear Brick: 1.2 L, 70 g/ft\textsuperscript{3}, 0/60/10

**Euro VI**

**Vehicle Speed (km/h)**

**Cumulative NO\textsubscript{x} (g/km)**

**Scr**
- Front Brick: 2.0 L, Cu-based
NH₃ Formation over TWC

\[ \text{NO}_x + \text{H}_2/\text{CO} \leftrightarrow \text{NH}_3 + \text{CO}_2 \]

\[ \text{Engine Out NO}_x \]

\[ \text{Post-TWC NH}_3 \]

\[ \text{Engine Out H}_2 \]

\[ \text{Engine Air / Fuel Ratio} \]

\[ \text{15.0, 14.0, 13.0} \]

\[ \text{Post-TWC NO}_x \]

\[ \text{Cum NH}_3, \text{NO}_x \text{ (moles)} \]

\[ \text{0, 0.01, 0.03, 0.05, 0.07, 0.09, 0.11, 0.13, 0.15, 0.17} \]

\[ \text{0, 200, 400, 600, 800, 1000, 1200} \]

\[ \text{Vehicle Speed (km)} \]

\[ \text{NH}_3/\text{NO}_x \text{ ratio is always greater than 1 over SCR for maximum conversion efficiency} \]
The Multiple Roles for TWC

Engine Operation

Lean

\[ \text{C}_x\text{H}_y + \text{O}_2 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{C}_x\text{H}_y + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2 \]

\[ \text{CO} + \text{O}_2 \leftrightarrow \text{CO}_2 \]

\[ \text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2 \]

\[ \text{NO}_x + \text{H}_2 \leftrightarrow \text{NH}_3 + \text{H}_2\text{O} \]

Stoic.

\[ \text{NO}_x + \text{CO} \leftrightarrow \text{CO}_2 + \text{N}_2 \]

Rich

CO Conversion

Hydrocarbon Oxidation

NO\textsubscript{x} Conversion

Pt Pd Rh ? OSC

\[ \Rightarrow \text{TWC design is critical for PASS} \]
Experimental Design

- Engine: 2.2L, stratified-charge developed by GM R&D
- Controller: d-SPACE with Micro-autobox
- Transient Dynamometer Equipped with Horiba Emission Benches, MKS FTIRs, and V&F H₂/O₂ Analyzer

I: Pd vs. Pd/Rh

- Investigate the effect of Rh and OSC for NH₃ formation

II: Pd vs. Pd/Pd/Rh/Pd/Pd/Pd

- Investigate the effect of Pd, Rh, and OSC for NOₓ reduction & CO/HC Oxidation

- Pd Brick: no OSC
  - 200 g/ft³, 0/200/0
- Pd/Rh Brick: Std. OSC
  - 70 g/ft³, 0/60/10
- Aged in RAT H cycle for 50 hrs
Modular Converters for TWC Design

Modular testing allows to characterize the individual components in TWC
NH₃ Formation over Pd-only vs. Pd-Rh

→ Pd/Rh catalyst with OSC makes much less NH₃ compared to Pd only catalyst
HC conversion efficiency over Pd only catalyst was much higher than that over Pd/Rh with OSC.
NO$_x$ Reduction Efficiency over TWC

NO$_x$ reduction in Lean Exhaust

(Shinjoh et al., 2004)

$\rightarrow$ Not much benefit of using Rh in terms of NOx efficiency under lean environment
OSC Effect on CO and HC Efficiency

HC conversion efficiency was great over Pd-only catalyst, however CO efficiency is strongly linked with Rh and OSC.
CO Conversion during Rich Operation

GHSV = 30,000 (rich) − 50,000 (lean) h⁻¹

CO is removed by water gas shift reaction over Rh/OSC

→ CO is removed by water gas shift reaction over Rh/OSC
Challenges

- High NH₃ Efficiency
- PGM & OSC Optimization
- NH₃ storage beyond 450 °C
- High Temp. NOₓ Efficiency
- Stable TWC under Lean Env.
- Stable SCR under Reducing Env.

TWC Technology
- Pd-only, No OSC
- Pd+Rh, Low OSC
- Pd+Rh, High OSC

SCR Technology
- ~ Zero Storage Capacity beyond 450 °C
- Cu-SCR
- Fe-SCR

Thermal Durability
- Degreened SCR
- After Lean/Rich (RAT) Aging at 750 °C

Oxygen Tolerant Universal Aftertreatment
Summary

• PASS concept: a universal, oxygen tolerant aftertreatment system for SI engines
  – Minimize PGM while improving fuel economy potential

• TWC technology that maximizes NH$_3$ production and CO/HC conversion under slightly rich conditions is the most important element in PASS
  – Modular TWC experiments guided us how EO emission interacts with Pd, Rh, and OSC components in TWC
  – Most NH$_3$ was produced from the Pd only catalyst
  – WGS reaction may be the most effective way to reduce CO during rich operations
THANK YOU!

Breaking the paradigm...

NOW green and fun to drive can go TOGETHER

Leading a Transformation in the Industry