

Investigation of LEV-III Aftertreatment Designs

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ABSTRACT

Proposed LEV-III emission level will require improvements in NMOG, CO and NO_x emissions as measured over FTP and US06 emission cycles. Incremental improvements in washcoat technologies, cold start calibration and catalyst system design are required to develop a cost effective solution set. New catalyst technologies demonstrated both lower HC and NO_x emissions with 25% less platinum group metals (PGM). FTP and US06 emissions were measured on a 4-cylinder 2.4L application which compares a close-coupled converter and close-coupled + underfloor converter systems. A PGM placement study was performed with the close-coupled converter system employing these new catalyst technologies. Emissions results suggest that the placement of PGM is critical in minimizing emissions and PGM costs.

INTRODUCTION

The LEV-III regulations are the new California/Section 177 State criteria for pollutant regulations anticipated to commence in 2014. The transportation industry is currently in discussion with the California Air Resources Board (CARB), and adaptation of the final LEV-III requirements is expected in early 2011. The expected main highlights of the new regulations will be:

- Full useful life aftertreatment test requirements. Emission durability of 150K mile levels.
- New FTP emission standards for PC/LDT1/LDT2 (<8500 GVW) vehicles

- New FTP emission standards for MDV2 (8.5-10K GVW) and MDV3 (10-14K GVW) trucks
- New particulate matter (PM) standards
- New SFPT III off-cycle emission standards for all vehicle classes (including MDV)
- Gasoline certification fuel specifications will contain 10% ethanol (E10)

The LEV-III FTP emission standards are expected to be stated as an additive NMOG + NO_x standard in place of the separate standards that exist today. There will be an expansion of available emission categories. A summary of the existing and proposed standards are listed in [Table 1](#).

There are several key elements of the LEV-III regulation that will challenge aftertreatment design. There will be an 8 year phase-in to achieve a SULEV fleet average for PC/LDT1/LDT2 vehicles. SFPT II standards will be measured at full useful life mileage compliance levels. US06 requirements are expected to challenge current catalyst volume requirements. ULEV70 and ULEV50 capabilities must be evaluated, and the upcoming SULEV fleet average will mandate the most cost effective engine and aftertreatment systems for regulatory requirements. The impact of E10 certification fuel effects on 50°F and 20°F emissions, and the new particulate matter (PM) and evaporative emission requirements will need engineering efforts, but will not be addressed here.

Table 1. Summary of the proposed LEV-III standards

Vehicle emission category	Existing NMOG standards ^a (g/mi)	Existing NO _x Standards ^a (g/mi)	Combined NMOG+NO _x standards (g/mi)	Proposed NMOG+NO _x emission standards ^b (g/mi)
LEV	0.090	0.070	0.160	0.160
ULEV	0.055	0.070	0.125	0.125
ULEV70	-	-	-	0.070
ULEV50	-	-	-	0.050
SULEV	0.020	0.010	0.030	0.030
SULEV20	-	-	-	0.020

^aThese emission certification levels are for a 120,000-mile durability basis

^bThese proposed emission certification levels are for a 150,000-mile durability basis

This paper sets out to investigate aftertreatment design for the LEV-III emission requirements. Previous works on optimizing catalyst design have focused on lowering rhodium content (1), optimizing the balance between PGM usage based on their commodity prices (2,3,4), and washcoat advance development studies (5). The effects of substrate cell density and diameter for optimal emissions and system backpressure has also been reported (6).

This paper sets out to further the development efforts demonstrated in earlier works by demonstrating LEV-III capable aftertreatment design solutions using current engine technologies. This is done by focusing our effort on PGM placement, catalyst volume usage and exhaust architecture in close-couple (cc) and cc + underfloor (uf) system designs.

CATALYST TECHNOLOGY COMPARISONS

In previous work, Wuttke (1) et al. demonstrated the capability of a new catalyst technology to significantly reduce Rh loadings on several vehicle applications. This technology is now the baseline “Production” catalyst technology used to compare to the “New” catalyst technology presented in this work. The goal of this “New” technology is to enable further PGM savings and/or the achievement of SULEV tailpipe standards.

Table 2 describes the catalyst substrates and PGM concentrations used for the catalyst technology comparisons. Designs A and B were evaluated on two different vehicles. Note that design B has 25% less Pd and Rh than design A. Higher PGM concentrations using design C were applied to both catalyst technologies and evaluated on a 4-cylinder vehicle. The front catalyst in design C used a 7.0 g/l Pd on the front 900/2.5 substrate without any Rh.

Table 2. Front and Rear Catalyst Specifications for Technology Comparison

Design	Front Catalyst				Rear Catalyst			
	Vol (L)	Sub (cpsi/mil)	Pd (g/l)	Rh (g/l)	Vol (L)	Sub (cpsi/mil)	Pd (g/l)	Rh (g/l)
A	0.65	600/3.5	2.95	0.14	0.65	400/4.5	0.61	0.14
B	0.65	600/3.5	2.21	0.11	0.65	400/4.5	0.46	0.11
C	0.65	900/2.5	7	0	0.65	400/4.5	0.53	0.11

DESCRIPTION OF TEST VEHICLES/ CALIBRATIONS

FTP emission testing was used to compare the “Production” and “New” washcoat technologies across both a 4-cylinder and a single bank (left) of an 8-cylinder vehicle. The 4-cylinder application employed an engine calibration that utilized a leaner fuel-air cold start strategy and numerous deceleration fuel cut-offs throughout the FTP75 test cycle (See Figure 1) compared to the 8-cylinder vehicle (See Figure 2). Both the 4 & 8 cylinder front catalysts bed temperatures reached 350°C within 19 seconds after the FTP75 cold start. The goal of this study was to demonstrate emissions performance robustness across different calibration/vehicle strategies, while minimizing washcoat technology cost and complexity.

CATALYST AGING

Both catalysts in this study were dynamometer aged on the Chrysler 2-mode exothermic aging cycle to simulate 150,000 equivalent miles of field aging. The peak catalyst bed temperature was 950°C during the hot-lean mode.

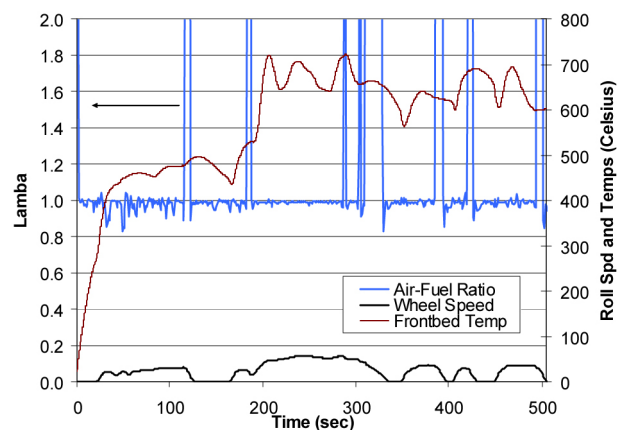


Figure 1. 4-Cylinder Catalyst Temperatures and Air/Fuel Control for Bag1

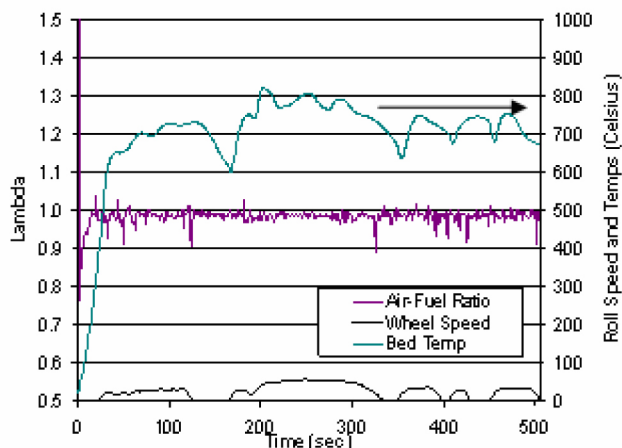


Figure 2. 8-Cylinder Vehicle. Left Hand Side Catalyst Temperatures and Air/Fuel Control for Bag 1

0.065 wt. g/mile. Similarly for NO_x emissions the “New” technology has lower emissions than the “Production” technology, 0.025 to 0.045 wt. g/mile.

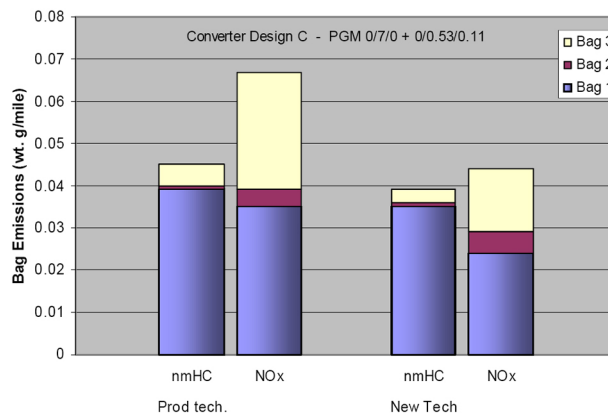


Figure 4. FTP Bag Emissions on the 4 Cylinder Vehicle at C PGM Loadings

CATALYST TEST RESULTS

Figure 3 presents the FTP results of the 4 cylinder and 8 cylinder vehicles. All results are an average of three FTP tests per condition. With respect to the 4-cylinder vehicle, the “Production” technology with A PGM has 25% more PGM than the “New” technology with B PGM. Overall NMHC are equivalent about 0.058 wt. g/mile. The “Production” technology at the higher PGM loading had lower NO_x emissions, 0.065 wt. g/mile compared to the “New” technology at 0.072 wt. g/mile.

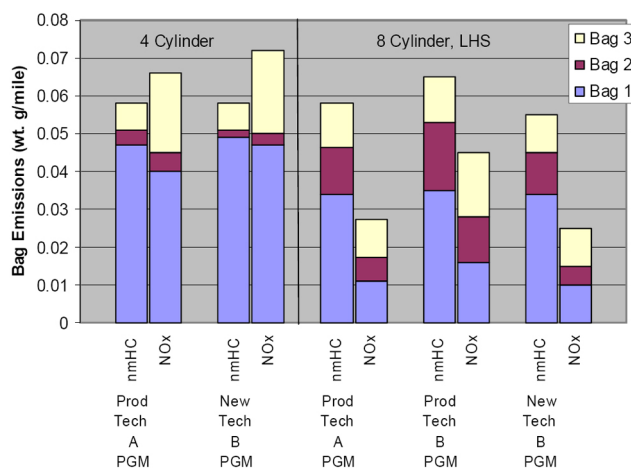


Figure 3. FTP Bag Emissions on the 4 and 8 Cylinder Vehicles at A and B PGM Loadings

Three comparisons were performed on the 8-cylinder vehicle. The “New” technology with lower PGM (B PGM), has equivalent or better NMHC and NO_x emissions than the “Production” technology (A PGM). At the equivalent PGM concentrations (B PGM), the “New” technology has lower NMHC emissions than the “Production” technology, 0.055 to

The catalyst technologies were also compared on the 4-cylinder vehicle at the higher PGM C concentrations. Results again show the benefits of the “New” technology. NMHC emissions were reduced from 0.045 to 0.039 wt. g/mile with the “New” technology and NO_x emissions were reduced from 0.067 to 0.045 wt. g/mile.

Results of the catalyst technology comparisons clearly demonstrate the benefits of the “New” technology catalyst. It appears to be robust to both application and PGM concentrations.

LEV-III SYSTEM DESIGNS

A current PZEV system with secondary air injection was compared with a system using the “New” technology to evaluate its potential for achieving SULEV emission levels. A three catalyst, single converter system with a total catalyst volume of 2.47 liters was designed as the PZEV solution. The details of each brick can be found in Table 2. A 900/2.5 cpsi substrate is used in the first position to increase available surface area for washcoat and allow rapid light off. The mid and rear substrates are 600 cpsi to allow the washcoat to work more efficiently in each of those positions. There are slight differences in PGM loadings. Design E with the “New” technology has no Rh in the front catalyst and slightly higher Rh concentration in the mid catalyst than designs D1 and D2.

In addition to the one converter close-couple system architecture, designs D1 and E, the “Production” technology system was also tested as a close-coupled + underfloor system, design D2, to determine the limitations of such system to achieve PZEV emission levels.