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Concept, Loading and Calibration Effects on the Emission Performance of NG-TWC for HD Engines

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Abstract

The environmental impact of heavy-duty vehicles powered by natural gas is considered to be less harmful compared to Diesel vehicles. Consequently, the share of vehicles using either compressed natural gas (CNG) or liquified natural gas (LNG) is expected to increase in the coming years. Since most Euro VI compliant engines operate with stoichiometric air-fuel ratio, the aftertreatment system (ATS) requires efficient three-way catalyst. With ever increasing prices on platinum group metals (PGM) over the past few years, three-way catalysts products have been exposed to wild fluctuations in cost that have had great impact on their affordability. Given that stoichiometric operation is the most widely used calibration of heavy-duty natural gas engines, the trade-off between efficiency, calibration and PGM cost must be constantly reset. This study focuses on the evolution and transition from bimetallic palladium-rhodium (Pd:Rh) concepts to trimetallic platinum-palladium-rhodium (Pt:Pd:Rh) three-way catalyst (TWC) concepts where a reduction in PGM loading through washcoat improvements and catalyst architecture supported by catalyst simulation software can be achieved, while keeping emissions at comparable or better levels and exploring the effects of different calibrations to the overall performance.

Introduction

Future developments in the automotive sector will be driven by a mix of technologies in which internal combustion engines (ICEs) will still have a role to play [1, 2, 3]. In a pathway to carbon-neutral mobility, research dedicated to developing low-carbon and alternative fuels is also increasing. Natural gas (NG) and biogas represent one of the most concrete alternatives, and its use is increasingly promoted in transport, both for energy security and local air quality reasons [4,5]. The absence of long hydrocarbon chains and aromatics makes natural gas a cleaner fuel than gasoline or diesel and able to guarantee lower gaseous emissions [6,7]. The abatement of gaseous emissions resulting from the combustion of natural gas and biomethane is traditionally handled using three-way catalysts on engines operating stoichiometrically [8,9]. Particle Number (PN) emissions from NG ICEs do not usually require control by particle filters [10] to meet the most recent emission limits e.g. EURO VI. If an emissions control device is applied, associated robust on-board diagnostic methods must also be implemented [11,12]. The three-way catalysts are complex, in the sense that multiple simultaneous reactions take place over a narrow window of operating conditions [13]. From these, the oxidation of methane causes the added difficulty of taking place at higher temperatures [14,15] requiring the use of Pd, which is the most active precious metal to catalyze the reaction in large quantities. Given the sharp price increase precious metals have experienced in recent years [16], three-way catalysts are required to have flexibility in terms of formulation, loading and ratios to ensure cost impact is minimized and performance is preserved. In this work, we study the effect of PGM loading, ratio and calibration on the emission performance of a three-way catalyst for heavy-duty applications by means of experimental testing in the laboratory and on the engine bench, supported by catalyst simulations performed with Exothermia software.

Experimental

Test Methodology

The test methodologies employed during the study included: Synthetic gas bench testing of laboratory-sized TWC samples, emission performance of full-size prototype TWC samples by means of engine dyno testing and catalyst simulation software.

For a given engine calibration, reduction of PGM loading must be accompanied by PGM ratio adjustments to help compensate the overall reduction in PGM content.

The model generated in the course of this study can be used to make theoretical predictions of the behavior of modified samples during the WHTC on the same engine. This provides a powerful, cost-effective and reliable method to perform catalyst optimization and concept design.

Engine calibration plays a decisive role in the behavior of a TWC under WHTC conditions. For the studied samples, the best calibration is that where fuel cut-off events take place and help oxygenate the surface of the catalyst, though this is accompanied by an increase in NO_x emissions, it also decreases the CH_4 and NH_3 peaks, helping to keep a more balanced emission mix with respect to calibrations not featuring fuel cut-off.

The ECU 2 dataset used also had a wider lambda window, allowing for changes in TWC concept to have a less dramatic effect on emissions. i.e. Pd:Rh and Pt:Pd:Rh TWCs with very different loadings and ratios can keep emissions under the legal limits. With a more restricted lambda window, such as that of the ECU 1 dataset, a change from Pd:Rh to Pt:Pd:Rh with a simultaneous significant reduction in PGM loadings would be expected to perform very poorly.

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