Heavy Duty Gas Engines integrated into Vehicles

EUROPEAN COMMISSION
Horizon 2020
H2020-GV-2014
GA No. 653391

Deliverable No.	HDGAS D3.1	
Deliverable Title	Output from catalyst model looking at ageing impact	
Dissemination level	**Confidential (CO)**	
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Status	**Final**	2016-04-20

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Acknowledgement:

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

1 - AVL - AVL List GmbH - AT
2 - BWR - Borgwarner Ludwigsburg GmbH - DE
3 - BOSCH - Robert Bosch GmbH - DE
4 - DAI - Daimler AG - DE
5 - DINEX - Dinex Ecocat OY - DK
6 - FPT - FPT Industrial S.p.A. - IT
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9 - MAN - MAN Truck & Bus AG - DE
10 - POLIMI - Politecnico di Milano - IT
11 - RCD - Ricardo UK Limited - UK
12 - SAG - SAG Motion GmbH - AT
13 - TNO - Nederlands organisatie voor toegepast natuurwetenschappelijk onderzoek - NL
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16 - UASE - Hochschule Esslingen - DE
17 - UNR - Uniresearch BV - NL
18 - VOLVO - Volvo Technology AB - SE
19 - VIF - Virtual Vehicle Research Center - AT

Disclaimer:

This project has received funding from the European Union's Horizon 2020, programme for research, technological development and demonstration under grant agreement no 653391.

Executive summary

One of the main goals in the field of transportation is reduction of emissions, and usually the reduction focuses on CO_2 emissions. Natural gas and its blend with diesel are good options to reduce CO_2 emissions of regular diesel fueled trucks. At the moment, Euro VI standards can be achieved with stoichiometric natural gas engines. However, to reduce CO_2 emissions even more, natural gas fueled lean-burn trucks which meets present Euro VI and future regulations need to be developed. One of the challenges is an after treatment system (ATS) which decreases the emissions of each vehicle below regulations limits. Euro VI emission standards require also a good durability and performance of the catalyst even after 700 000 km/ 7 years. The challenge will be even greater, since durability of the after treatment system should be predicted for each application.

The exhaust gas after treatment system is a permanent and key part of current vehicles. Its development has continued already over 60 years, and emission levels of the vehicles have been decreased significantly. The development of exhaust gas cleaning strategy is always a joint process of emissions strategy, engine development, emission control and after treatment systems.

The Figure shows feasible layouts for exhaust gas ATSs of natural gas and dual-fuel heavy-duty trucks such that post Euro VI emission standards can be met. Emission conversion of stoichiometric NG engine can be carried out with a three-way catalyst (TWC). The question will be in the future how ammonia (NH_3) and nitrous oxide (N_2O) emissions can be minimized, and how improvements in fuel economy changes the raw emissions of the stoichiometric engines.

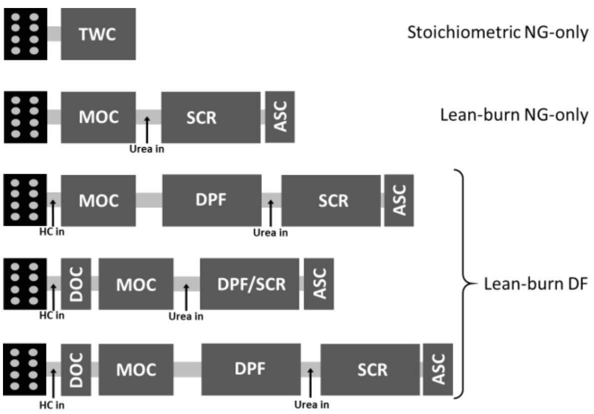

Figure 1: Possible layouts for exhaust gas after treatment systems for stoichiometric and lean-burn natural gas fueled engines. (TWC=three-way catalyst, MOC = Methane Oxidation Catalyst, DOC= Diesel Oxidation Catalyst, SCR=Selective Catalytic Reduction converter for NO removal, ASC = Ammonia Slip Catalyst, DPF= Diesel Particulate Filter, and DPF/SCR= Combined converter of DPF and SCR).

Lean-burn conditions in NG combustion requires more complex ATS to clean exhaust gases. Methane oxidation catalyst (MOC) converts CO and CH_4 emissions and provides small quantities of NO_2 for selective catalytic reduction (SCR). SCR converts NO_x emissions with NH_3 to N_2 and H_2O. Ammonia slip catalyst (ASC) prevents NH_3 emission, which may be caused by SCR at low temperature and during rapid changes in engine operation. The present challenges in development of ATS for lean-burn natural gas fueled engines are to improve sulfur resistance of the MOC and understand how raw emission of the engine, and in particular, how methane affects the performance of SCR.

To meet very stringent emissions standards with a dual-fuel engine, diesel particulate filter (DPF) and possibly diesel oxidation catalyst (DOC) need to be installed to the ATS as well. The function of DPF is to collect and burn particulates, formed during diesel fuel combustion. DOC removes emissions of C2+ hydrocarbons, and provides NO_2 for passive soot removal and for fast-SCR reaction. DOC may also increase temperature inside MOC and thus may promote its CH_4 conversion level. The challenges are: to improve sulfur resistance of MOC, but also fundamental understanding about the effect of hydrocarbons the performance of the system. Formation of NO_2 over the ATS will be a crucial question for the system operation that emissions can be converted at low temperatures to reach the best possible results.

The durability aspect of the catalysts is and will be even more a critical question now and in the future, since Euro VI and post Euro VI legislations for heavy-duty vehicles require a good durability of the ATS. Thus in the laboratory studies the research was focused on fundamental understanding about aging phenomena of the catalysts to clarify how and why the catalyst performance changes after long-term use.

Exhaust gas emissions of stoichiometric natural gas engines can be converted with a TWC. However, always when methane is converted, ammonia and nitrous oxide emissions are possible. Formation of such emissions were studied and the following conclusions can be drawn. Methane can be converted with a TWC on both rich and lean side, but the NO emission can be converted only under rich conditions. In principle, the simultaneous conversion of the emissions is carried out by altering oxygen amount of the raw emission. Based on the laboratory results, NH_3 formation occurs on rich side whereas N_2O emission formation is probable under lean conditions. NH_3 formation in a TWC is time-dependent reaction and its concentration in exhaust gas increases as a function of time spent on rich side. The possible solutions to minimize NH_3 and N_2O emissions could be (i) strict lambda control of the engine, (ii) shorten the time of rich pulses, and (iii) optimization of catalyst composition with better OSC materials and other noble metal combinations (Pd-Pt-Rh). NO concentration of exhaust gas affects at least the NH_3 emission of the fresh catalyst; the higher the NO concentration, the higher the NH_3 emission even though same CH_4 conversion can be reached. Aging studies showed that catalyst operation window changed and if the same calibration is applied over the vehicle life-time the emissions may change. ATS performance can be improved over its life-time with a good control of exhaust gas oxygen concentration. Overall solutions to decrease NH_3 and N_2O emissions will be a joint development of catalyst composition, engine, and calibration strategies.

Methane oxidation under lean conditions produces less CO_2 emissions and is more efficient compared to stoichiometric natural gas combustion. The present study clarified the challenges of the after treatment system of lean-burn natural gas engine. Sulfur deteriorates the activity of MOC. Methane can be converted with 90% conversion at 450°C with a MOC. To understand why MOC deactivates after long-term use, the catalysts were characterized and their activities in CH_4 oxidation were studied. According to literature study and laboratory experiments, sulfur poisoning phenomenon is due to (i) formation of surface $PdSO_4$ layers over PdO particles, and (ii) water vapor stabilization of reaction intermediates like $Pd(OH)_2$. To improve catalyst activity, active metal particles should be tailored so that (i) oxygen is still mobile after sulfate formation, (ii) sulfate of active metal is less stable than the active form of active metal in methane oxidation. High O_2 should be used for lean methane oxidation to avoid harmful N_2O formation and to maximize NO_2 amount in the exhaust gas stream to promote low temperature NO removal with SCR system.

The NH_3-SCR activity of two state-of-the-art SCR catalysts, namely a Vanadium- based system and a Cu-zeolite, both coated onto corrugated metal sheets, was investigated under conditions relevant for the EAT systems of lean-burn NG vehicles. The laboratory studies showed greater DeNOx performances for the Cu-zeolite catalyst. Upon co-feeding ammonium nitrate, however, the low-temperature SCR activity of the V-based sample was significantly enhanced, in line with previous literature. In the case of the V-based catalyst, no effect associated with co-feeding methane was detected, which seems promising for its application to the aftertreatment of emissions from natural-gas fueled vehicles. The impact of both ammonium nitrate and methane on the activity of the Cu-zeolite catalyst is being addressed in the continuation of the present studies.

A simulation exercise has shown the magnitude of the challenge of controlling methane emissions in a lean exhaust system. The simulation showed that the exhaust temperatures over the World Harmonised Transient Cycle (WHTC) for a dedicated natural gas application, were generally lower than the light off temperature of the current state of the art methane catalyst, leading to ~ 6% methane exhaust control. This did not allow the Euro VI tailpipe target of 0.5 g/kWh tailpipe methane limit to be met. An electrically heated methane oxidation catalyst was simulated and this was able to meet the tailpipe legislative target. However, this led to a fuel penalty of ~ 10%. The outcome of the initial simulation has been fed into the lean burn engine development work package to ensure a focus on reducing engine out emissions of methane and maintaining heat in the exhaust system to minimize any exhaust aftertreatment thermal control fuel penalty. This also sets the challenge of developing advanced methane catalyst with lower light off temperatures.

Acknowledgment

This project has received funding from the European Horizon 2020 Programme for research, technological development and demonstration under grant agreement no 653391