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Catalyst Aging Method for Future Emissions Standard Requirements

Dmitry Ignatov, Carsten Küpper, Stefan Pischinger
Institute for Combustion Engines, RWTH-Aachen University

Michael Bahn, Winston Betton, Oliver Rütten, Rolf Weinowski
FEV Motorentechnik

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ABSTRACT

This paper describes an alternative catalyst aging process using a hot gas test stand for thermal aging. The solution presented is characterized by a burner technology that is combined with a combustion enhancement, which allows stoichiometric and rich operating conditions to simulate engine exhaust gases. The resulting efficiency was increased and the operation limits were broadened, compared to combustion engines that are typically used for catalyst aging. The primary modification that enabled this achievement was the recirculation of exhaust gas downstream from catalyst back to the burner.

The burner allows the running simplified dynamic durability cycles, which are the standard bench cycle that is defined by the legislation as alternative aging procedure and the fuel shut-off simulation cycle ZDAKW. The hot gas test stand approach has been compared to the conventional engine test bench method. Comparisons of catalysts aged on the hot gas bench and an engine dynamometer showed similar results within the tolerance band.

An urban driving cycle was also run on the test bench with a diesel exhaust system that included a particulate filter working in regeneration mode. The drive cycle simulation on the test bench was able to provide an exhaust gas temperature profile within the catalyst, which represented the same thermal load as in the vehicle. The aging progress was monitored by a dynamic light-off measurement procedure.

The capability to produce heavily aged three-way catalysts on the test bench down to the OBD limit was also investigated. The profile of catalyst damage and the resulting effect on oxygen storage capacity and emissions, could be varied by adjusting the bench aging parameters.

INTRODUCTION

The global vehicle emission legislation defines the requirements in reducing emission levels. As the emission limits for new vehicles operating under the mandated drive cycles are being restricted, a greater focus is also placed on emission sources that were not originally covered. The durability of exhaust aftertreatment systems is a major issue in order to assure an overall reduction in vehicle fleet emissions in the future. Therefore, the durability requirements have been increased to higher mileage, such as with 160,000 km for EURO V [1] and up to 150,000 miles for the SULEV emission standard [2]. Additionally, tighter thresholds for OBD malfunction detection will be applied. In the past only the OBD limits for THC or NMHC emissions were defined; however, the new requirements also include detection of NOx emissions.

To test the limits for catalysts that represent those with high mileage or severe field damage, these catalysts have to be produced by vehicle durability runs or alternatively by artificial means. The durability testing is generally the final step in engine development, before launching a new vehicle to market. This testing requires more time to complete when higher emission durability target mileages are set. There is a tremendous demand to reduce development time and very often changes in engine design and engine control parameters influence aftertreatment development. In later stages of development it is difficult to evaluate emission performance after the catalyst aging process. Therefore, legislators and car manufacturers are working on procedures to reduce durability testing time and to implement alternative methods to generate aged catalysts.

In order to define suitable aging methods, the main aftertreatment deactivation mechanisms have to be analyzed first. Aftertreatment deactivation and malfunction mechanisms depend on the aftertreatment function and working principles and are as numerous as the aftertreatment technologies used. The most common aftertreatment systems are three-way-catalyst systems used for standard stoichiometric gasoline applications, oxidation catalysts used for the lean exhaust gas of diesel engines and NOx reduction catalysts for lean exhaust gas with and without an additional reducing agent, as well as particulate filters. The aging process for these aftertreatment types occurs in the field through physical, chemical and thermal aging mechanisms, with different intensity and different sensitivity to chemical substances and maximum exhaust temperatures.

CATALYST AGING EFFECTS IN THE FIELD

CHEMICAL AGING

Chemical aging is caused by oil and fuel components. For gasoline engine three-way applications, the main chemical aging effect is caused by oil additives. Wear inhibitor additives, such as ZnDDP, contain phosphor and zinc, which work on the catalyst by blocking the surface and reducing the binding strength [3]. Additional poisoning effects were observed by Ueda, with a glaze formation of $Zn3(PO4)2$ on the catalyst and lambda sensors [4]. Oil and fuel bound sulfur is stored in the catalysts. Sulfur poisoning is also reported in a large number of publications as in [5] for diesel oxidation catalysts and in [6] for diesel and gasoline lean burn after treatment NOx adsorber technology. Other fuel components, such as lead and manganese, are known to be strong catalyst poisons that play a minor role in countries with highly restrictive emission regulations, due to the high fuel quality.

In general oil consumption of modern engines is being reduced and fuel qualities are improving. Therefore, chemical poisoning is no longer the major cause for catalyst deactivation or malfunction. Thermal aging is now the primary cause for catalyst deactivation or malfunction.

THERMAL AGING

Thermal deactivation occurs at high temperatures and is strongly aggravated by exhaust gas property changes. High temperature gradients can lead to damage of the substrate and impact washcoat adhesion. Both rich and lean changes are responsible for local exothermic reactions in the catalyst, due to the storage characteristic needed for normal operation. Thermal aging is described in a variety of publications [7, 8 and 9]. Major mechanisms commonly described in those publications include the following:

- Reduction of the surface area and pore volume of the washcoat
- Precious metal agglomeration of the active centers
- Oxygen storage material destruction

As an example the precious metal active center agglomeration that took place over a durability run can be seen in fig. 1. A palladium particle growth from less than 10 nm to up to 50 nm was observed by TEM-EDX microscopic analysis, comparing fresh and aged catalysts.

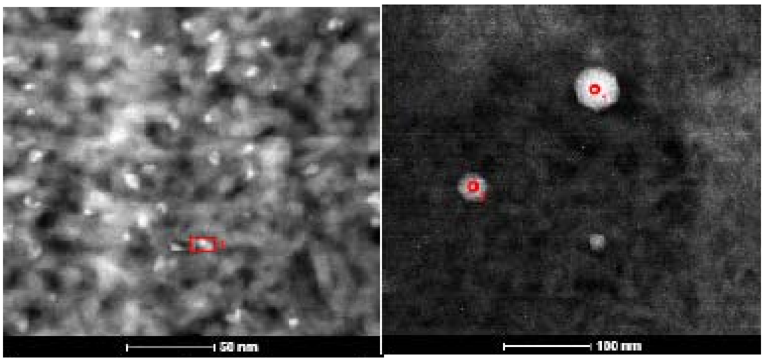

Fig. 1: Comparison of vehicle fresh (left) and aged (right) washcoat active center diameter and distribution

Durability testing is focused on the high temperature aging procedures, because thermal aging is the dominant effect for the most common aftertreatment systems. When defining an appropriate aging simulation method the mechanisms presented have to match. The aging method has to simulate an overall catalyst temperature field and also local endothermic and exothermic reaction as in the vehicle. In order to fulfill this requirement a hot gas aging bench has to deliver exhaust gas with exhaust properties similar to the engine. It is therefore mandatory to have a wide operation range flexibility to adjust air to fuel ratio, mass flow, exhaust temperature and exhaust composition.

DESCRIPTION OF THE HOT GAS AGING TEST BENCH

Catalyst aging test benches with combustion engines are used due to the availability of combustion engines, which have proven their robustness in the field. Also, the idea of providing exhaust gas produced by an engine is generally seen as being the closest to real aging of a catalyst in a vehicle. Nevertheless, the engine type often used for aging is not the one connected to the aftertreatment system. Therefore, not only emission composition, but also the flow to the catalyst and the distance of the catalyst from the engine, does not exactly represent the original vehicle conditions. In order to cope with the high thermal stress and corrosion of the exhaust line, typically the exhaust valves and exhaust system are modified to increase the lifespan of these engines, when used for catalyst aging. Nevertheless, a major inconvenience can be seen in the inefficient production of exhaust gas. Out of the total fuel energy, roughly one third is converted into the exhaust enthalpy increase. Additionally, the lifespan of these engines is limited and component failure often increases the aging time and can uncontrollably pollute the aftertreatment system. One way to overcome this is through the use of hot gas test stands. The catalyst aging bench described here is based on a technology, which is derived from flow controlled burners for liquid fuel. The catalyst aging bench uses exhaust gas recirculation as primary modification to allow a wide operation range and to simulate the highly dynamic behavior of engine exhaust (see fig. 2).

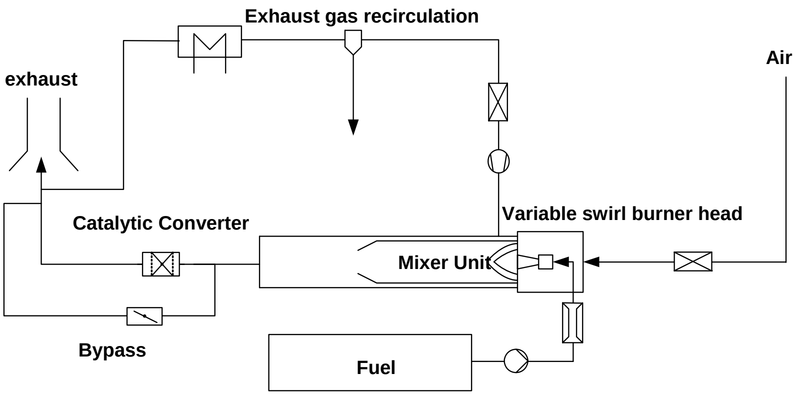

Fig. 2: Hot gas aging test bench schematic

The burner solution is represented in figure 3. It is characterized by a variable high swirl apparatus to improve mixture formation, featuring high pressure liquid fuel injector taken from a gasoline direct injection combustion engine. The air flow is split up into a primary and a secondary air sleeve around the injector. The primary flow is in direct contact with the injection spray cone and is swirl controlled. In addition, the outer secondary air flow can be throttled. The combustion chamber is designed to recirculate exhaust gas in an internal primary path within a flame tube. The internal exhaust gas recirculation assures a stable ignition. Design characteristics and function are described in [10].

Exhaust gases that are recirculated in a secondary path from downstream of the catalyst and cooled down to less than 100°C are fed to the outer jacket, which reduces the wall temperature to enable the burner walls to withstand the high temperature stoichiometric operation. The temperature reduction from the adiabatic combustion temperature of more than 2000°C down to a usable value is also necessary to represent typical engine exhaust gas properties. The secondary exhaust gas recirculation is fed starting at an axial position downstream of the flame tube, where the ignition of the fresh air - fuel mixture has successfully been carried out. Still, higher secondary exhaust gas rates bring a certain amount of cold exhaust gas back to the primary reaction zone and reduce the fresh air flow. In order to enable a stable flame position over the complete operation range the variable swirl and the secondary air flow to the burner can be modified.

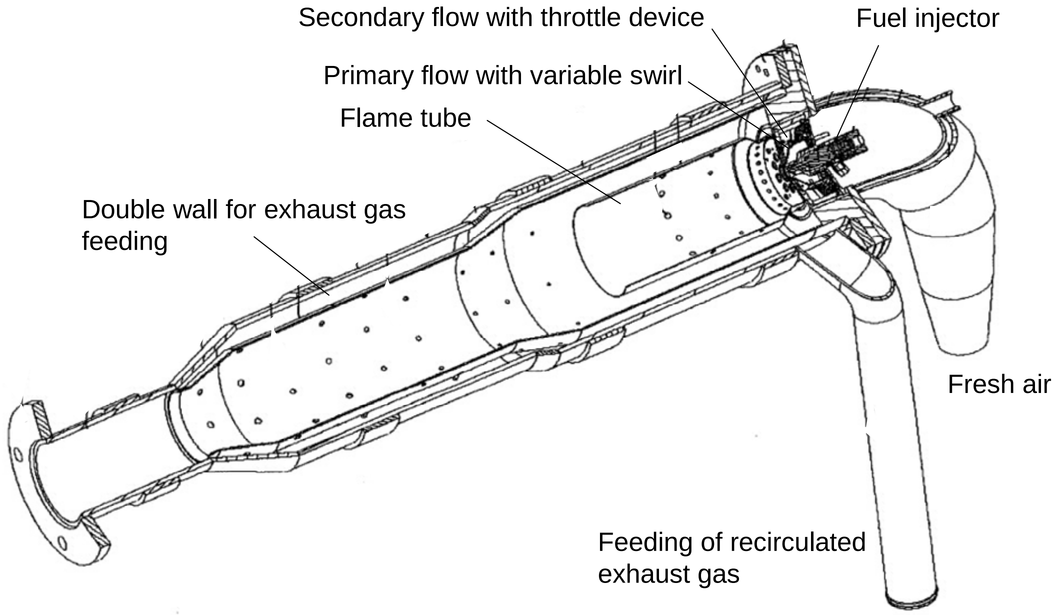

Fig. 3: Variable swirl burner

Burners are typically designed for single point operation or operation following an operation line, where the temperature can be controlled by reducing the amount of fuel and having a leaner mixture. The characteristic of the catalyst aging bench burner without secondary exhaust gas recirculation is close to the minimum exhaust gas flow borderline (fig. 4). The minimum flow is required to cool the burner walls. By recirculating exhaust gas after passing it through the catalyst, a wide operation map of mass flow and temperature can be realized. The optimized combustion system is able to supply stoichiometric exhaust gas in a flow range from approximately 10 gram / sec up to 120 gram / sec, within a temperature range of 400°C up to 1300°C (fig. 4).

In figure 4 the borderlines of the useable operation map can be seen. The maximum useable flow of approximately 120 gram / sec is defined by air and exhaust gas recirculation compressors, but can be pushed to higher values with higher power compressors. The lower flow limit of approx. 10 gram / sec is determined by the minimum air flow required for flame stabilization. The flame stability limit line is given by mixing secondary exhaust gas to this operation point. The 400°C low temperature limit downstream of the burner is realized at the maximum exhaust gas recirculation rate possible, without reaching the combustion limit. The combustion is limited by flame blow-off, when combustion position moves downstream at high exhaust gas rates and inner hot gas recirculation is no longer able to ignite the mixture safely. Gas flow division allows gas temperatures of less than 400°C and gas flow values down to less than 10 gram / sec in order to simulate the part load area of a combustion engine.

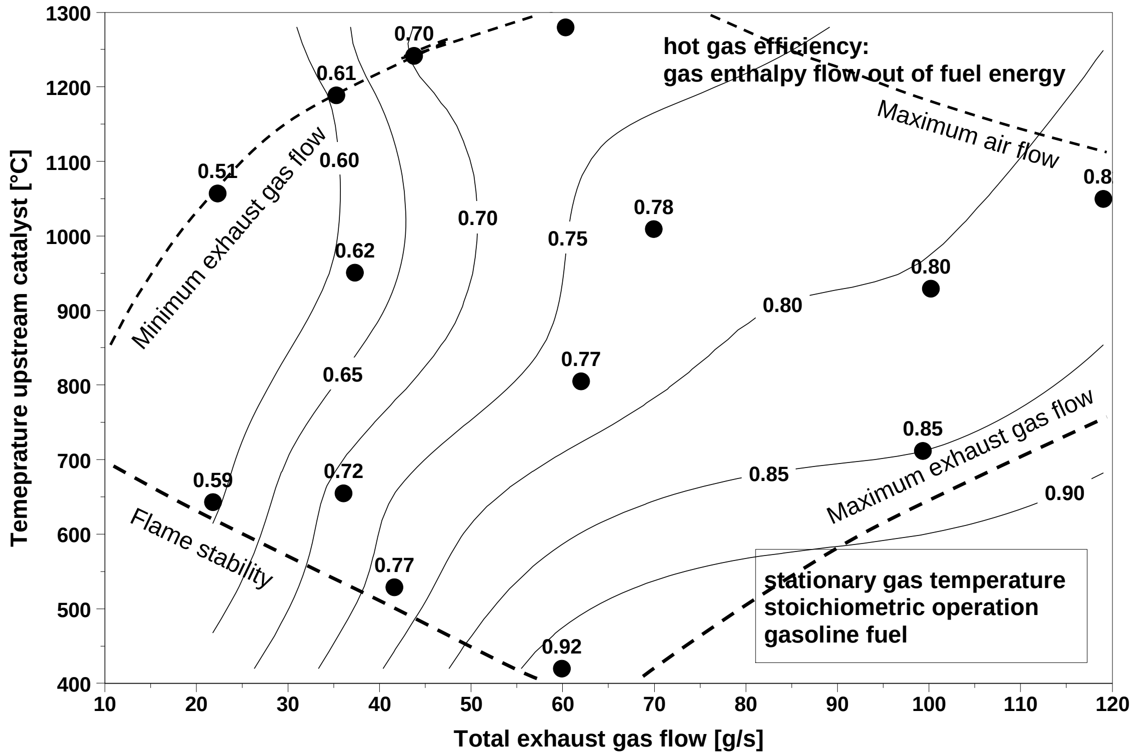

Fig. 4: Hot gas aging bench efficiency map and operation limits

In fig. 4 the isolines represent operation points of same efficiency. The efficiency is defined as exhaust gas enthalpy flow out of fuel energy flow and depends directly on the exhaust gas recirculation rate. The efficiency can be increased with higher rates of exhaust gas recirculation. Several components in the exhaust gas recirculation line do not withstand high temperature, especially the air flow meter and the compressor. The recirculated gas has to be cooled down for this reason. In order to compensate for the efficiency loss, a heat exchange unit can heat up the recirculated exhaust gas before feeding it to the burner jacket. Additionally, preheating the fresh air can increase the efficiency, which is a common process enhancing feature of burner technology. The injection system, with the high pressure injector, currently limits the air temperature to values of approximately 100°C.

The efficiency of the actual solution reaches 80% in the relevant operation points for thermal aging, which is in a range of 800°C up to 1000°C (fig. 4). The efficiency is seen as the resulting gas enthalpy flow delivered to the catalyst divided by the total fuel energy flow used. On the contrary, a gasoline engine has approximately 33% efficiency (exhaust gas enthalpy out of fuel energy) if no special modifications are applied. The possibilities to increase the exhaust temperature on a production engine through calibration are limited, due to the fact that normal engines are limited by exhaust component temperature. An exhaust temperature increase can be reached within certain boundary conditions through the use of exhaust valves and exhaust manifold for higher heat resistance and insulation measures. Additionally, when using a burner, the desired high exhaust temperature does not necessarily require a high mass flow like a combustion engine. Thus, the exhaust flow can be set independently of the chosen exhaust temperature level and an additional reduction in fuel consumption is possible by reducing the exhaust mass flow.

Figure 5 shows the exhaust emission characteristic of the burner at a stationary point with gasoline, which is typically part of durability cycles. In this figure the NOx and THC emissions are on a very low level known from burner combustion. Therefore, rich mixtures are strongly correlated to CO emission. At stoichiometric conditions, the slow CO oxidation of the burner combustion systems leads to the presence of a CO volume of 0.2%. Emission testing was done by standard engine test bench gas analyzers.

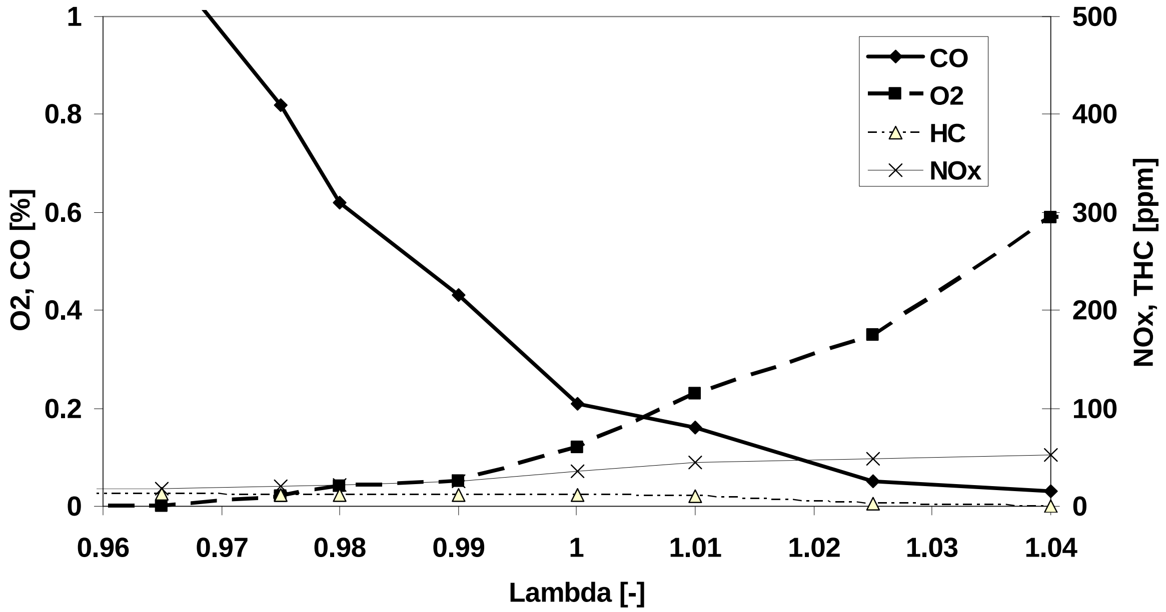

Fig. 5: Burner exhaust emission at 60 gram / sec, 800°C

For multi bank exhaust systems, bank deviations in exhaust temperature can occur as with engine use. Individual bank-specific cold exhaust flow lines for a multi-catalyst set up compensate this effect. The resulting deviation in temperature can easily be kept within the +/- 5°C tolerance band.

Dynamic changes are realized quickly through feed air and swirl adjustments, as well as through exhaust gas recirculation control. The dynamic can be easily adjusted by controlling the gas flows and gas properties to the conditions found with combustion engines.

AGING TEST BENCH METHODS

STANDARD BENCH CYCLE SIMULATION

The test bench can be used to run a full drive cycle simulation and simplified aging procedures that represent identical thermal loads and are composed of catalyst exhaust flow characteristics found in extreme real world driving conditions. Typical aging cycles consist of the following elements simulating these situations:

- Stoichiometric operation with lambda oscillation at the temperature limit, before component protection is switched on in the engine control
- Rich operation at borderline temperatures, which are used for component protection
- AFR change from rich to slightly lean, which occurs when excess oxygen reaches the catalyst as can be the case when the lambda control to stoichiometric is switched on, or by uneven cylinder distribution or close catalyst position to the cylinder and exhaust gas post reactions

- AFR change from stoichiometric or rich mixture to pure air flow representing the fuel shut off operation used in engine control for fuel consumption reduction

A good correlation between engine test bench aging results and the vehicle fleet testing programs is claimed, when both aging programs provide the same accumulated thermal load to the catalyst [11]. This is of course only true within certain boundaries of temperature and lambda, which are used for the tests. The simulation of the vehicle standard road cycle by a simplified standard bench cycle is adopted by EPA and European legislation. This is based on the comparison of the thermal loads and follows to a theoretical Arrhenius approach for catalyst deactivation energy. The aging time required to reach the equivalent thermal load is calculated with the bench aging time (BAT) formula [11]. The calculation defines the thermal load on the catalyst, when it is on the test bench in the standard bench cycle and on the vehicle in the standard road cycle. The temperature is divided into bins (ranges) and for each bin the time at this temperature on the vehicle is calculated. Using a bench specific reference temperature representing the same thermal load the required time on the bench can be calculated.

$$BAT = A \cdot \sum_{\min}^{\max} \Delta t \left(e^{\frac{R}{Tr} - \frac{R}{Tv}} \right)$$

$$\begin{aligned} &with: \\ &A = chemical\ deactivation\ correction \\ &\Sigma = sum\ over\ all\ temperature\ bins \\ &\Delta t = time\ at\ temperature\ bin\ in\ the\ vehicle \\ &R = reactivity\ constant \\ &T_r = effective\ reference\ temperature\ bench \\ &T_v = midpoint\ temperature\ vehicle \end{aligned}$$

R is proposed to be 17500 as a catalyst type specific deactivation time constant for LEVII aftertreatment and R=18500 for all other vehicles [11]. A is proposed to be 1.1. This value adjusts the catalyst aging time to account for deterioration from sources other than thermal aging of the catalyst [11].

Figure 6 shows the standard bench cycle run on the hot gas test bench. The resulting aging time for identical thermal loads, as required for 120,000 mile durability, was for the example provided and calculated to be less than 200 hours.

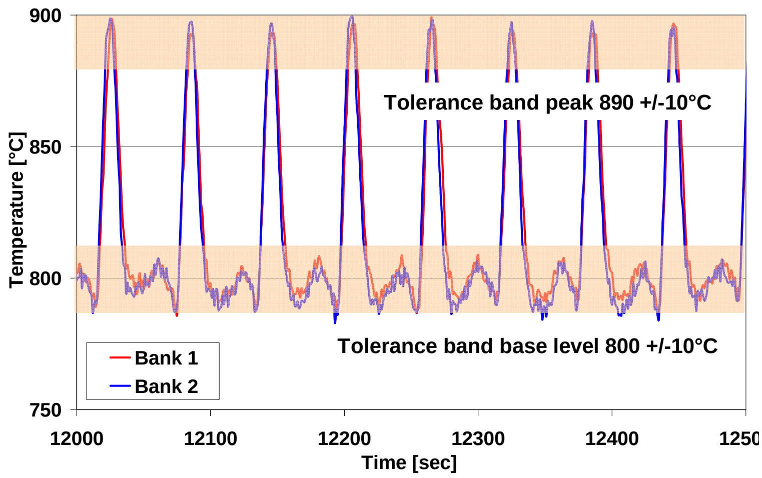

Fig. 6: Standard bench cycle run on aging test bench

Another aging cycle used for full useful life testing study [12] was developed and described as ZDAKW, which focuses on the fuel shut-off situation that is mainly responsible for the catalyst aging under European driving conditions. Figure 7 shows the measurement of a shut-off entry situation from full load of a production vehicle on a chassis dynamometer. As seen in the illustration, the switch from rich to lean can cause a temperature increase by producing stoichiometric operation for a short period of time. The figure shows the delayed exothermic reaction in the catalyst and an increase in the bed temperature after more than 5 seconds. Measurements taken from several positions relative to the catalyst even showed a hot spot for this specific shut-off situation of 30°C higher temperature on a position aside from the center of the catalyst brick. The severity of this situation led to defining the shut-off re-entry as a key aging factor.

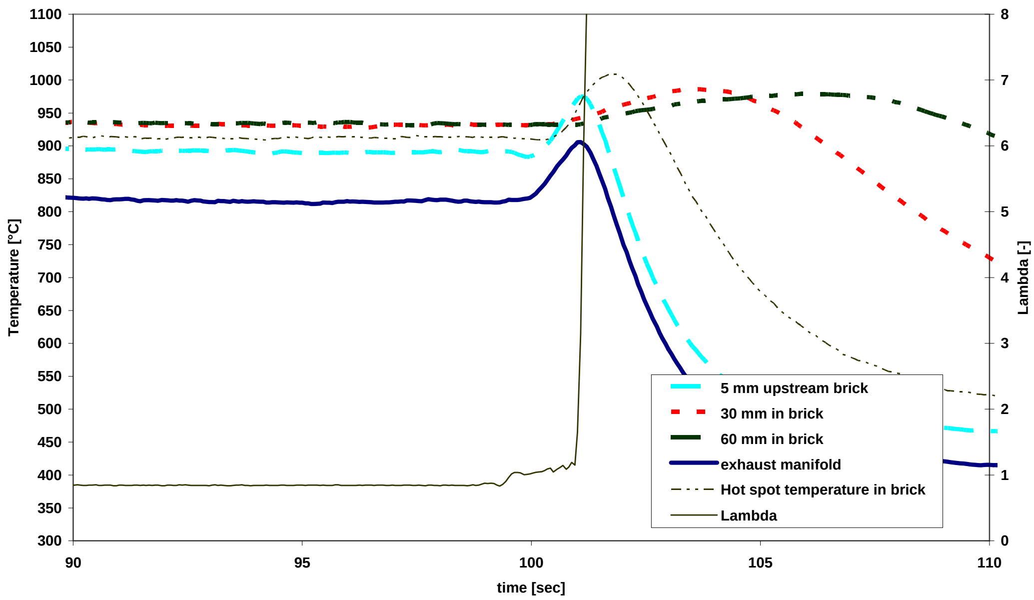

Fig. 7: Shut-off situation measured in a vehicle

The ZDAKW cycle repeats a comparable situation for a time originally defined to be 96 hours for the EURO III 80,000 km equivalent. The catalyst aging test bench is able to produce dynamic gas mixture and gas temperatures, corresponding to the vehicle measurements. The temperature dynamic was observed in the vehicle to be approximately 100°C / sec (fig. 7) and was reproduced on hot gas aging bench (fig. 8). Figure 9 shows a comparison of FTP results in a standard gasoline vehicle with a catalyst aged on the hot gas aging test stand and on an engine dynamometer, resulting in emissions within a tolerance band of +/- 5% of the emission threshold. The accumulated tailpipe emissions are added in figure 10. NOx and THC behavior were found to be almost identical concerning light-off and emission breakthrough in the later stages of the test. The deviation in CO was caused before light-off and cannot be related to the catalyst properties.

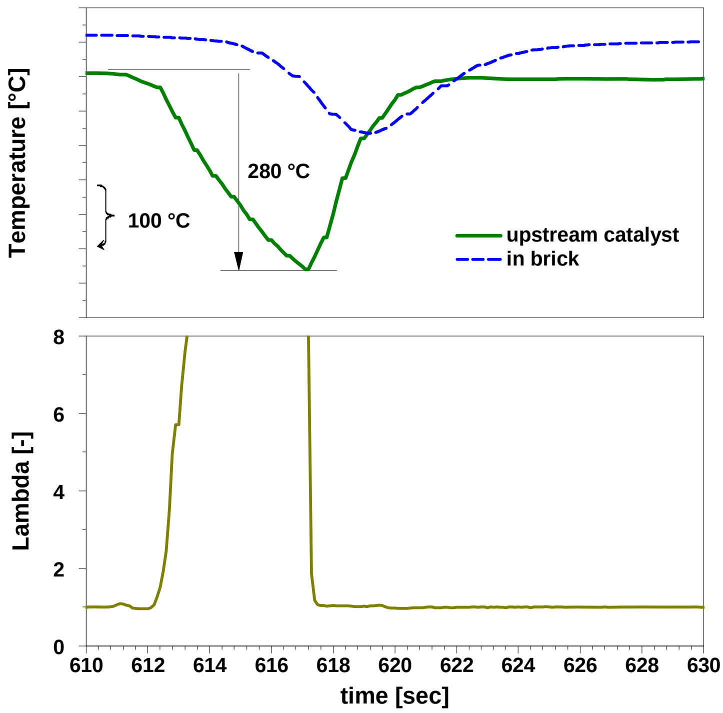

Fig. 8: ZDAKW cycle on hot gas test bench

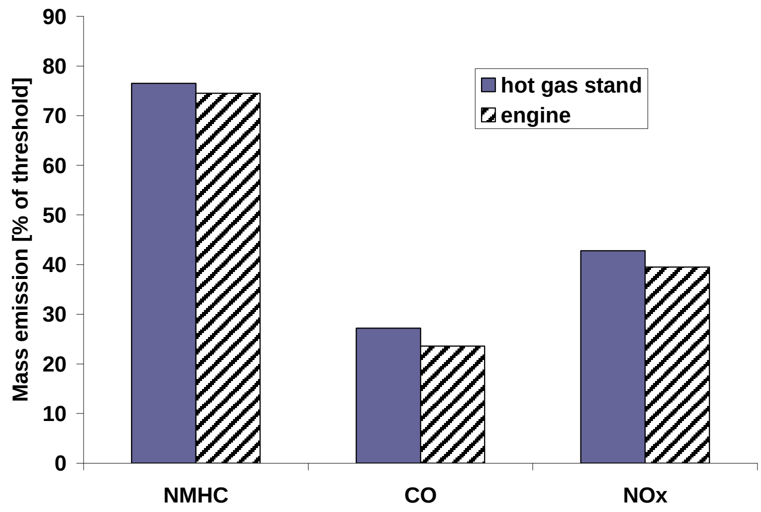

Fig. 9: FTP emission result comparison with different aging methods for ZDAKW catalysts

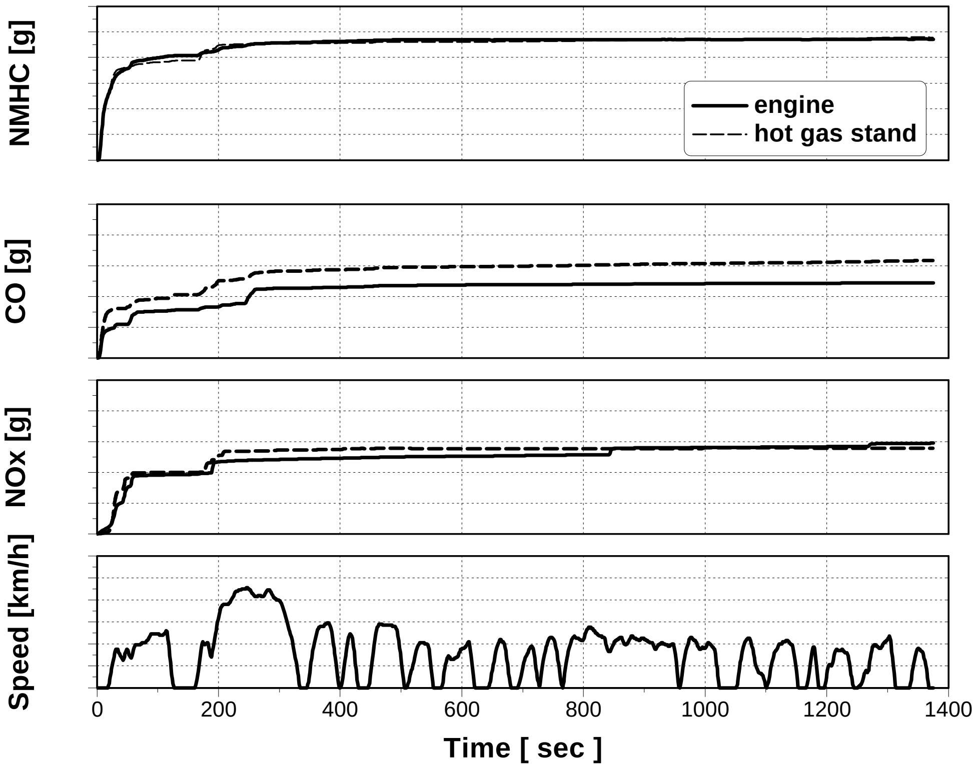

Fig. 10: FTP emission comparison with different aging methods

DRIVE CYCLE SIMULATION OF DIESEL EXHAUST BEHAVIOR DURING FILTER REGENERATION

A critical situation for diesel exhaust systems with particulate filter is during filter regeneration, which is frequently activated. Typical regeneration intervals, for the standard road cycle, are in a range of 1000 km. The realization of the regeneration operation on a hot gas aging test bench was done with diesel fuel operation and post injection of diesel fuel into the lean exhaust gas provided by the burner. The use of diesel fuel injection provides an unburned hydrocarbon emission composition comparable to diesel engine exhaust emissions during regeneration. The regeneration simulation was completed by providing the oxidation catalyst with the same dynamic gas profile as in a representative urban driving cycle. The oxidation catalyst produced the exothermic reaction to regenerate the filter by burning off the collected soot. Figure 11 shows the exothermic reaction of the regeneration cycle. The dynamic profile corresponds quite well to the profile of an engine. Other cycles, such as the NEDC, were also simulated in regeneration mode and could be reproduced in the relevant higher temperature area. In Figure 12, the temperature histogram is compared to the vehicle measurement.

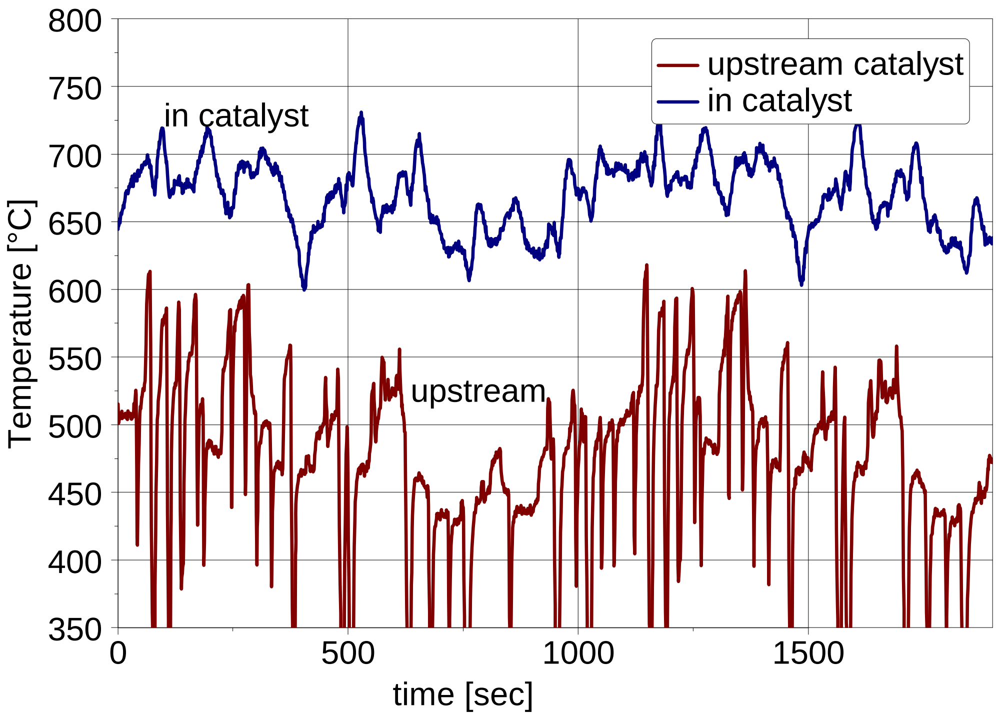

Fig. 11: Dynamic simulation of the drive cycle on the hot gas test stand

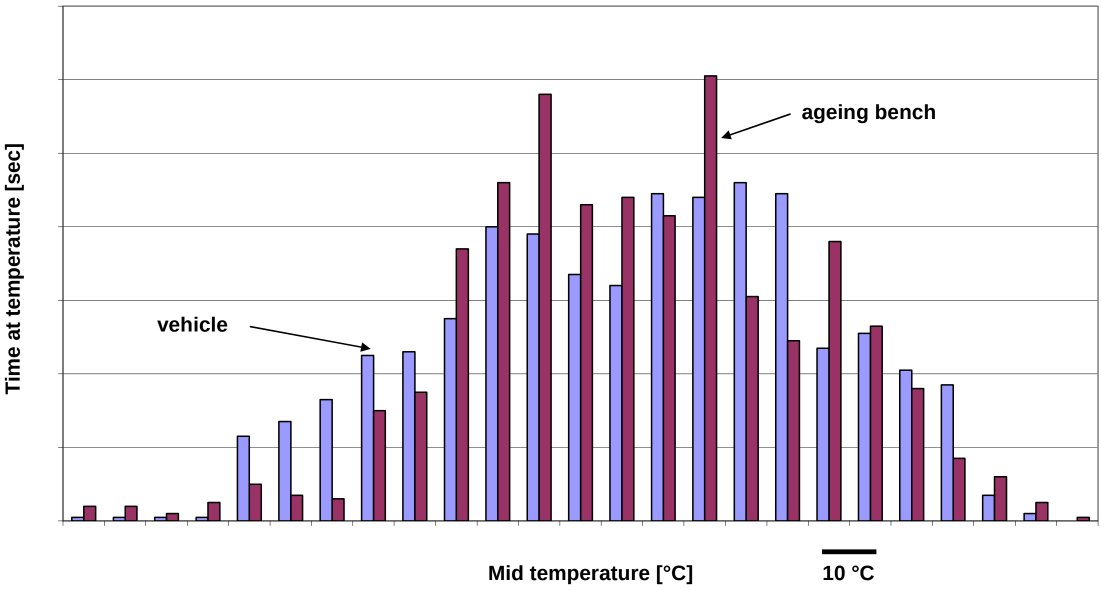

Fig. 12: Exhaust temperature histogram of the engine and hot gas test stand aging profile

Monitoring exothermic reaction for diesel aftertreatment systems is necessary, due to the fact that the oxygen storage evaluation method cannot be used as it is with gasoline engines. One possibility is the evaluation of light-off performance after cold start. Among other methods, this was investigated through the use of the hot gas test stand. A dynamic procedure was developed, due to the low temperature limitation of the burner and in order to be closer to the emission relevant light-off characteristics of the vehicle. The light-off tests started with shut off operation down to 180°C. Subsequently, the start of the burner was operated under gas flow conditions similar to the vehicle in idle, with lambda higher than 2. Additionally, the post injection of diesel fuel upstream of the oxidation catalyst was controlled to a defined level. The light-off evaluation of the oxidation catalyst was completed by a temperature measurement upstream of the catalyst and within first brick, defining the cross point as a criterion. This procedure correlated with the conversion start of THC.

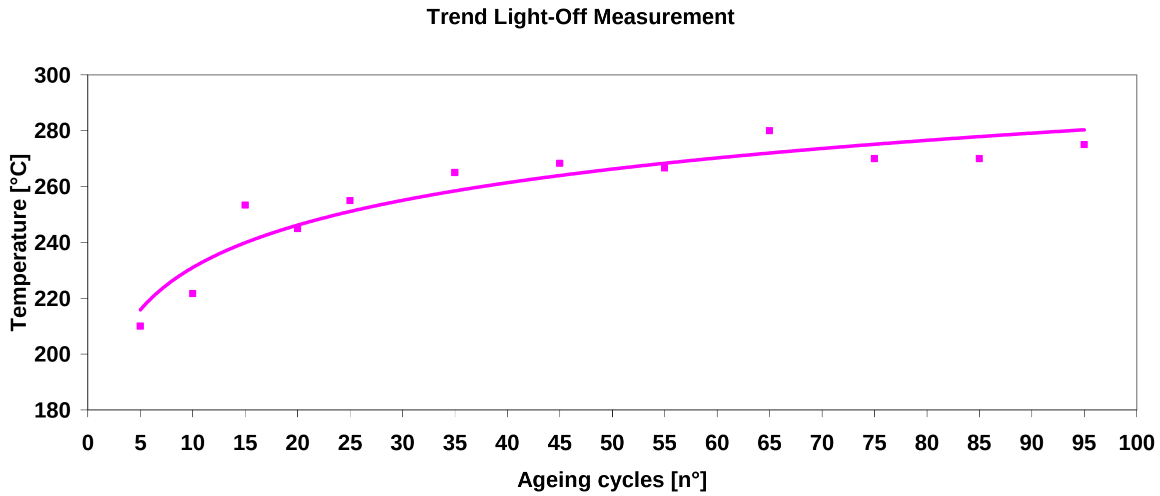

Fig. 13: Light-off upon aging of a DOC measured on hot gas aging test bench

The described program focused on diesel oxidation catalyst behavior. For particulate filter aging cycles, soot load generation has to be included, which can be completed through rich operating conditions at increased soot levels.

HIGH TEMPERATURE AGING FOR RAPID SIMULATION OF HEAVY CATALYST AGING OR DAMAGE

Legislation requires on board monitoring of emission-relevant components and especially the aftertreatment system. A malfunction of the aftertreatment system has to be detected when the defined OBD emission limits are exceeded, which is generally between 1.5 to 4 times higher than the full useful lifetime emission thresholds.

Proper OBD functionality requires that catalysts have to be aged to a point where the OBD monitor has to evaluate if the catalyst is still as good or close to the threshold level or is defective. In order to provide catalysts that are representative for typical damage or showing strong aging characteristics found in the field, catalysts are either produced on engine test bench with additional secondary air feeding high temperatures [13], oven aging [14], misfire generation on engine test bench, or directly in a vehicle on a chassis dynamometer. This paper describes how the catalyst aging test bench was used to search for appropriate methods.

Different aging strategies were investigated and analyzed in order to represent the characteristics needed for in-field aging. Specific focus was made on deteriorating the Oxygen Storage Capacity (OSC) and different emission species individually. The aging status monitoring of the catalyst was done by an OSC analysis over rich - lean and lean - rich jumps in order to be close to the current gasoline three-way catalyst monitoring in the field. This method can be directly applied to the catalyst aging bench (fig. 14). Methods for catalyst emission monitoring that were based on this method or similar lambda sensor-based methods are described in a variety of publications [15, 16, and 17]. The OSC methods are suitable for catalysts with high OSC values and where emission increase after light-off is strongly correlated with the OSC value. Alternatively, the dynamic light-off tests already described can also be employed on diesel oxidation catalysts, where OSC values are low and not directly correlated with emissions.

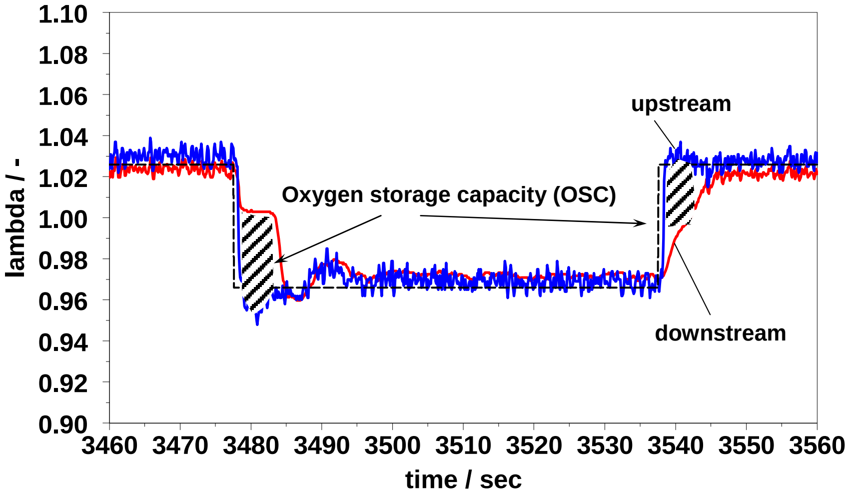

Fig. 14: Oxygen storage capacity measurement on hot gas test stand

As mentioned, there are a variety of major thermal aging mechanisms, which reduce the washcoat surface through sintering, produce precious metal agglomeration and damage the oxygen storage. Oxygen storage is needed for normal stoichiometric operation and lambda oscillation under operating conditions after catalyst light-off. Early light-off of the catalyst requires a strong catalytic reaction, which is deteriorating when precious metal dispersion is reduced after aging. The resulting aging effects on a catalyst aged on the hot gas test stand could be shifted to a desired level through a variation of the experimental setup.

Two major experiments were run with the aim to compare completely burned exhaust gas having a low oxygen level (configuration A) to exhaust where oxidation was still present (configuration B). In both cases the exhaust temperature in the catalyst was set to 1250°C. Secondary air was avoided in one experiment (configuration A), where completely burned exhaust gas was required. Configuration B was run with a rich base mixture from the burner and adding secondary air. The secondary air increased the exhaust temperature to the desired level. The secondary air reaction in the hot gas is shown in figure 15 for a lower base temperature. The time of the temperature increase through combustion at approximately 150 mm corresponds to the ignition delay. After an initial rapid combustion, a second phase with a slower combustion rate can be seen. This exhaust emission effect is known as slow CO oxidation from burners in general. The incomplete combustion was used to provide the catalyst with partly unburned gas and thus delivering oxygen to the catalyst.

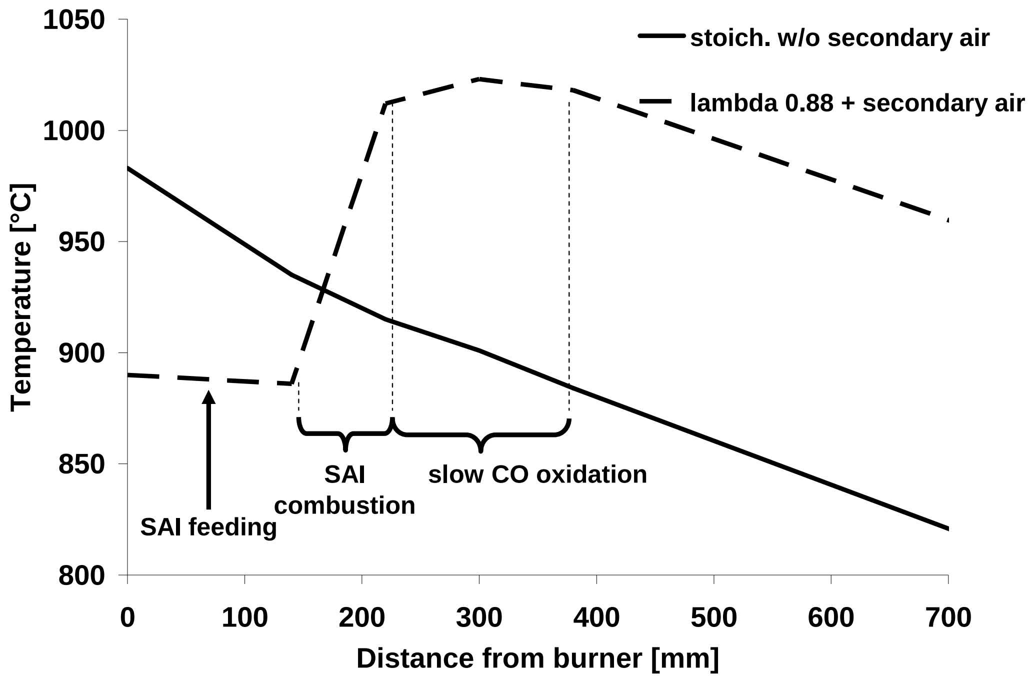

Fig. 15: Secondary air reaction / main and delayed oxidation used for configuration B

A comparison of the OSC destruction and emissions over time is illustrated for both configurations (A) and (B) in figure 16. After each aging step emission tests were run and oxygen storage capacity analyzed. Both catalysts were stabilized by stoichiometric operation at medium temperature levels on the aging test bench before running the NEDC tests. The aging effect on oxygen storage capacity is strong at first for configuration A, but the emission increase is only limited. OSC reduction is then reduced and emissions start increasing strongly for method (A). This basic non-linear correlation of the OSC and emissions has been reported by various authors [18].

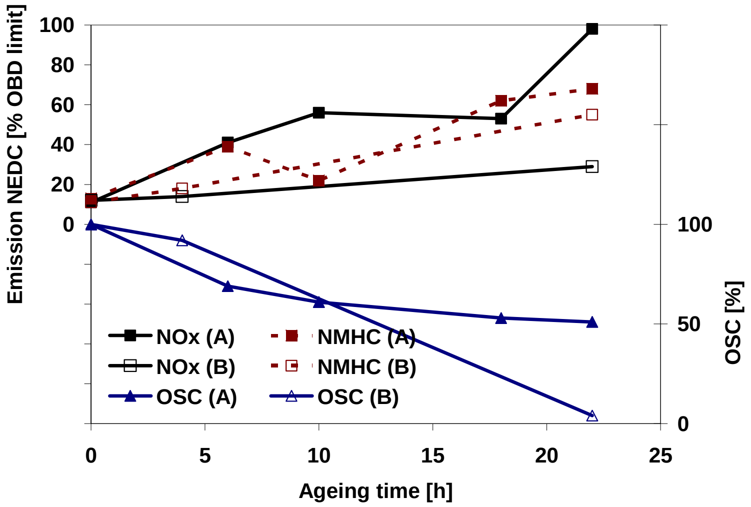

Fig. 16: Comparison of aging methods (A) and (B)

The faster OSC destruction was found with method (B), which brought exhaust gas to the catalyst that was not completely burned. The local exothermic reaction of unburned CO close to the OSC material was assumed to be responsible for the stronger OSC destruction with this configuration. The experiment proves that different aging mechanisms are effective for the aging process. By exhaust gas property changes the aging effect can be shifted from stronger OSC destruction at moderate emission increase to moderate OSC destruction at stronger emission increase.

Figure 17 illustrates the tailpipe HC and NOx emissions for the strategy (B) after the initial first step and after 22 hours. The aging had almost no effect on the light-off temperature, but destroyed the OSC. The emission increase was linked to the OSC destruction and was still lower than OBD threshold.

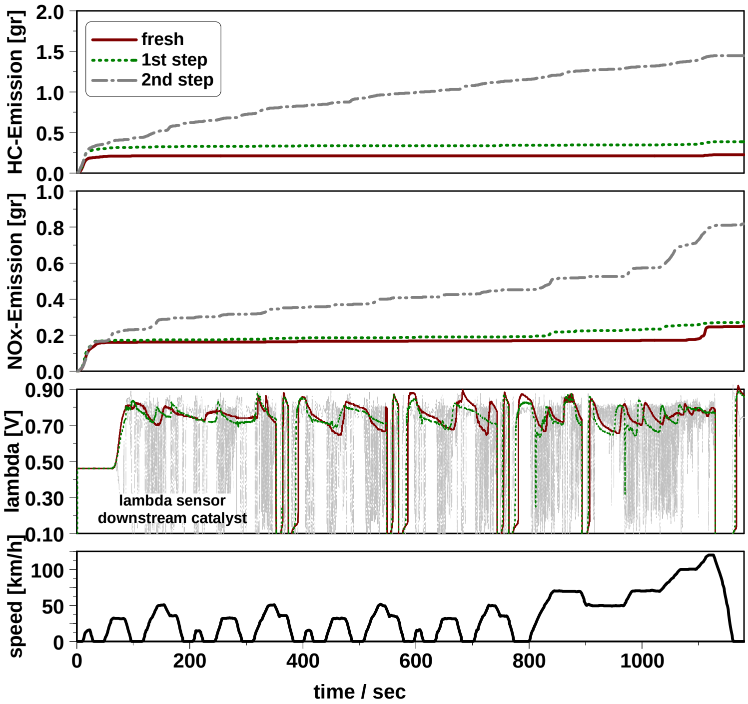

Fig. 17: NEDC emission with catalyst aged using method (B)

SUMMARY/CONCLUSIONS

This study presented an alternative method for simulating exhaust aftertreatment and specifically catalyst aging in the vehicle. The solution, based on a modified burner technique with variable high swirl for stoichiometric and rich operation, has the following major advantages compared to conventional durability testing in a vehicle or on an engine test bench:

- Large operation point flexibility with independent control of exhaust temperature and exhaust mass flow
- Two to three times higher efficiency for hot gas production compared to engine test bench use
- Robust solution, high repeatability and avoidance of uncontrolled influences from corrosion products
- Capability of exhaust gas reactivity modification

The solution that was developed was compared to vehicle and engine operation. The results shown in the catalyst aging effect were similar and within a tolerance band of +/- 5% of the limit for the gasoline three-way catalyst comparison. Gasoline and diesel aftertreatment system aging was realized by applying simplified aging cycles and vehicle drive cycles to simulate engine operation. Simulation of heavily aged or damaged catalysts in the field was completed through high temperature operation. The profile of catalyst damage and the resulting effect on oxygen storage capacity and emissions could be varied by adjusting the aging bench parameters. The major influencing parameters that were discovered were the aging temperature and the degree of combustion completion.

Oxygen storage analysis through a lambda wide range sensor over a rich - lean and lean - rich shift and a dynamic start up procedure to evaluate light-off performance were two procedures that were developed to monitor the aging process.

REFERENCES

1. European Commission, “Regulation (EC) Nr. 692/2008 of the commission,” rev. 18th of July 2008
2. California Low-Emission Vehicle Regulations, “§1961(a-e) The LEV II exhaust emission standards,” April 17, 2009
3. Lafyatis, D.S.; Petrow, R.; Bennett, C., “The Effects of Oil-derived Poisons on Three-Way Catalyst Performance,” SAE Paper 2002-01-1093
4. Ueda, F.; Sugiyama, S.; Arimura, K.; Hamaguchi, S.; Akiyama, K., “Engine Oil Effects on Deactivation of monolithic Three-Way Catalysts and Oxygen Sensors,” SAE Paper 940746
5. G. McCullough; R. Douglas and N. McDowell, “Deactivation of Oxidation Catalysts by Oil-Derived Sulphur,” SAE Paper 2004-01-1738
6. Erik Fridell and Magnus Skoglundh, “Model Studies of Sulphur Deactivation of NOx Storage Catalysts, “ SAE Paper 2004-01-0080,
7. Gerald Ruß, Rudolf Flierl, Dirk Kairies, “Katalysatorvergiftung von Ottomotoren durch Motorenöl,” MTZ 6/2005
8. E. Rohart, O. Larcher, C.Hédouin, M. Allain and P. Macaudière, “Innovative Materials with High Stability, High OSC, and Low Light-Off for Low PGM Technology,” SAE Paper 2004-01-1274
9. Paul Dagobert, Automobiles and Pollution, SAE, Warrendale, PA, USA, 1995, ISBN 1-56091-563-3
10. Bahn, M., "Herstellen von Alterungsgas für Abgasnachbehandlungssysteme", Patent Application, PCT/EP2008/006982, 26th of February 2008
11. Environmental Protection Agency Federal Register, “40 CFR Part 86 Emission Durability Procedures and Component Durability Procedures for New Light-Duty Vehicles, Light-Duty Trucks and Heavy-Duty Vehicles; Final Rule and Proposed Rule, Part IV,” January 17, 2006,
12. Johann Siebler, Maximilian Schreiner, Rainer Zimmer, Michael Rieser, Axel Hirschmann, Gunter Loose, Herwig Richter, Wolfgang Held, Manfred Rohlfs, «Gemeinsames Katalysatorprüfverfahren von Audi, BMW, Mercedes-Benz, Porsche und VW, » MTZ 4/94
13. Corkhill, W.J.; Douglas Gilchrist, R.,N., “Method and Apparatus for Aging a Catalyst”, UK Patent application, GB, 2356826A, 6.6.2001
14. Schmidt; Brady; Summers; Reizig; Brück; Breuer; “New catalyst preparation procedure for OBD II monitoring requirements,” SAE Paper 2001-01-0933
15. James C. Peyton Jones and Kenneth R. Muske, “Model-based OBD for Three-Way Catalyst Systems,” SAE Paper 2004-01-0639
16. Grant A. Ingram and Gopichandra Surnilla, “On-line Oxygen Storage Capacity Estimation of a Catalyst,” SAE Paper 2003-01-1000
17. James C. Peyton Jones, “Modeling Combined Catalyst Oxygen Storage and Reversible Deactivation Dynamics for Improved Emissions Prediction,” SAE Paper 2003-01-0999
18. Hepburn, J.,S.; Gandhi,H.S.; “The Relationship between Catalyst Hydrocarbon Conversion Efficiency and Oxygen Storage Capacity”, SAE Paper 920831

CONTACT INFORMATION

Oliver Rütten
FEV Neuenhofstr. 181
52078 Aachen
Phone +49/241/5689347

Mobile +49/1607463612
ruetten@fev.de

DEFINITIONS, ACRONYMS, ABBREVIATIONS

A Chemical deactivation correction coefficient

AFR Air Fuel Ratio

DOC Diesel Oxidation Catalyst

FTP Federal Test Procedure

NEDC New European Driving Cycle

NMOG Non Methane Organic Gases

NMHC Non Methane Hydrocarbon

OBD On-Board Diagnosis

OSC Oxygen Storage Capacity

R Reactivity factor

SBC Standard Bench Cycle

SRC Standard Road Cycle

SULEV Super Ultra-Low Emission Vehicle

TEM-EDX Trans Electronic Microscopy – Energy Dispersive X-Ray technology

Tr Reference temperature on test bench

Tv Mid-point temperature in vehicle

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