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Zero-Impact Emissions from a Gasoline Car with Advanced Emission Controls and E-Fuels

Zero-Impact Emissionen eines PKW mit Ottomotor durch innovative Abgasnachbehandlung und bei Verwendung von E-Fuels

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Abstract

This paper describes the implementation of an advanced emission control system on a gasoline demonstrator vehicle and the validation of the ultra-low pollutant emissions on sustainable renewable fuels. The gasoline demonstrator vehicle is equipped with a 48 V mild-hybrid powertrain with a turbocharged 1.5 l direct injection engine. The emission control system consists of a three-way catalyst (TWC) in close-coupled position, in combination with an underfloor catalysed gasoline particulate filter (cGPF), a second TWC and an ammonia slip catalyst (ASC). In a second phase, an electrically heated catalyst (EHC) is included as the first part within the close-coupled TWC.

The first part of the paper on pollutant emissions investigates the potential of the emission control system to reduce the initial cold-start emissions directly after engine start and the operation strategy of the ASC for a gasoline application. In addition to regulated pollutants, currently non-regulated emissions of PN10, NH_3 and N_2O are measured. Pollutant emission tests are conducted over a variety of conditions, beyond the Euro 6d RDE boundary conditions. This paper presents ultra-low pollutant emissions measured on an exemplary RDE aggressive test on the chassis dyno at ambient temperatures of 23 °C and -10 °C.

The second part of the paper looks into the validation of the ultra-low pollutant emissions achieved on reference petrol (E10) on two sustainable renewable fuels. Blue Gasoline is selected as an already available fuel, targeting at least 20% CO_2 reduction. E-gasoline is also tested as a mid-term available fuel to target 100% renewable content.

Kurzfassung

Diese Arbeit beschreibt zum einen die Integration und Bewertung eines fortschrittlichen Abgasreinigungssystems in einem ottomotorischen Demonstratorfahrzeug, zum anderen die Bestätigung des erzielten Niedrigemissionsniveaus für nachhaltig, erneuerbare Kraftstoffe. Bei dem Demonstratorfahrzeug handelt es sich um einen 48-V-Mildhybriden, welcher mit einem abgasturboaufgeladenen 1.5 l Ottomotor mit Direkteinspritzung ausgestattet ist. Das untersuchte Abgasreinigungssystem besteht aus einem Dreiwegekatalysator in motornaher Einbauposition sowie einem Unterbodensystem, welches sich aus einem katalytisch beschichteten Ottopartikelfilter, einem zweiten Dreiwegekatalysator und einem Ammoniakschlupfkatalysator zusammensetzt. In einer zweiten Projektphase wird ein elektrisch beheizter Katalysator als erste Komponente in motornaher Position verbaut.

Der erste Teil dieser Arbeit befasst sich mit dem Emissionsreduktionspotential des Abgasreinigungssystems direkt nach Motorstart. Des Weiteren wird die Betriebsstrategie des Ammoniakschlupfkatalysators für eine ottomotorische Anwendung untersucht. Neben den bereits begrenzten Schadstoffen werden auch die aktuell nichtlimitierten Emissionen PN10, NH_3 und N_2O gemessen. Die untersuchten Emissionstestzyklen spiegeln eine Vielzahl von Umgebungsrandbedingen wieder, welche über die der Euro 6d RDE Gesetzgebung hinausgehen. In dieser Arbeit wird das sehr niedrige Schadstoffemissionsniveau präsentiert, welches in einem beispielhaften RDE Fahrprofil mit aggressiver Fahrweise für die Umgebungstemperaturen von 23 °C und -10 °C gemessen wird.

Der zweite Teil dieser Arbeit bestätigt, dass das sehr niedrige, mit europäischen Referenzkraftstoff ROZ95 E10 erzielte Schadstoffemissionsniveau auch mit zwei nachhaltigen, erneuerbaren Kraftstoffe erzielt werden kann. Hierbei wurde Blue Gasoline als

bereits erhältlicher Kraftstoff gewählt, der eine 20-prozentige Absenkung der CO_2-Emission verspricht. Darüber hinaus wird ein mittelfristig verfügbares E-Benzin untersucht, welches aus 100% erneuerbarer Energie gewonnen werden soll.

Introduction

The impact of road transport to air quality and climate change has continuously improved with the introduction of new European legislation. To improve air quality and reduce health impacts in the EU, successive European emission standards have been introduced to decrease pollutant emissions from road transport vehicles. An overview of the step-wise reduction in NOx emission factors for passenger cars according to the Handbook of Emissions Factors (HBEFA) [1] is shown in Figure 1.

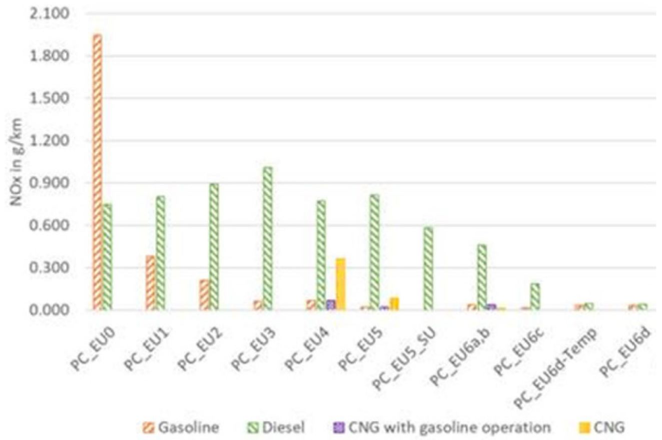

Figure 1 HBEFA factors for passenger car NOx emissions under warm operation [1]

Emissions under warm operation have nearly been eliminated for gasoline vehicles, compared to the levels before the existence of the standards. This is now also the case for gasoline PN and diesel NOx emissions with the introduction of the Real Driving Emissions (RDE) procedure towards Euro 6d. Good control of gaseous and particulate emissions under relevant actual operating conditions is ensured by testing a car on public roads and over a range of different ambient and driving conditions. The successive emission standards promoted innovation in catalyst and filter technology design as well as emissions control system layout. This allowed to significantly reduce the pollutant emissions within an integrated approach of powertrain development in addition to progress in engine and combustion technology. Examples of state-of-the-art systems for the latest Euro 6d passenger car standards include close-coupled catalysts for cold-start and low speed and load driving in the city, and underfloor catalysts for high speed and load area on the motorway for both diesel and gasoline passenger cars. Total catalysts and filter volumes are designed to cope with peak engine pollutant flow. On-road NOx and PN emissions have been reduced significantly as a consequence and this is confirmed by OEM data at Type Approval [2-3] and independent third-party testing [4-5].

Further evolution is expected towards Euro 7 for which the legislative development process is ongoing. It continues to consider modifications to limits and test procedures to ensure lowest possible vehicle pollutant emissions. The CLOVE consortium has worked on the topic on behalf of the European Commission and presented scenarios to the Advisory Group of Vehicle Emission Standards (AGVES) until April 2021. The actual Euro 7 proposal from the European Commission is expected in the second quarter of 2022, it was not yet available at time of writing of this paper. Research focuses on further reducing the remaining emissions during the initial cold-start phase for gasoline vehicles, as illustrated in Figure 2 for 3 Euro 6d-TEMP vehicles [6]. Also controlling currently non-regulated pollutants is investigated.

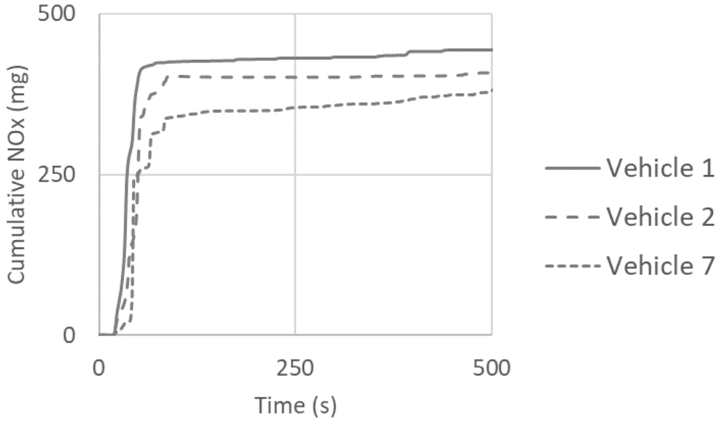

Figure 2 Euro 6d-TEMP gasoline NOx emissions are mainly from initial cold-start [6]

EU legislation reduced the fleet average tailpipe CO_2 targets in g/km for passenger cars to mitigate climate change. A new WLTP test procedure was introduced to make the emission targets more representable compared to those established on the NEDC. The fleet targets led to innovation in engine efficiency and hybridisation in addition to development of zero tailpipe emission vehicles. Regulations in the EU have also encouraged the development and incorporation of renewable fuels for transport with a view to reduce its carbon footprint through the Renewable Energy Directive. The most recent adopted version requires 14% of renewables to be applied in road transport on an energy basis. This is under further review as part of the European Commission 'Fit for 55 package' [7]. A new approach of requiring a minimum reduction in the carbon intensity of the fuels by 2030 makes it difficult to assess how much more ambitious this review will be. Although it opens the door to development of new type of fuels, for example e-fuels, the target levels within the proposal are not in line with the overall ambition to reduce EU's GHG emissions by 55% compared to a 1990 reference.

Recent focus of the legislator is on the introduction of zero tailpipe emission vehicles. the 'Fit for 55' package' is considering as one of the options to target 100% share of new vehicle sales as zero tailpipe emissions by 2035 to achieve carbon neutrality by 2050. However, it is expected the majority of new vehicles will be equipped with an internal combustion engine for decades to come in a worldwide context, which is important for global warming. Additionally, all emissions that can be reduced now will have a significant impact on mitigating climate change due to the cumulative effect of every gram of CO_2 emitted into the atmosphere. Consequently, it is key to further improve the efficiency of an electrified internal combustion engine. Moreover, it is essential to operate as much vehicles as possible on sustainable renewable fuels. Data [8-13] shows that a vehicle with an internal combustion engine meets the carbon neutral target, similar to a BEV on renewable electricity and a FCEV on green hydrogen.

Consequently, the electrified internal combustion engine can contribute to achieve the sustainability goals. This work looks into further reduction in initial cold-start emissions with the implementation of a state-of-the-art emission control system on a gasoline vehicle. The work includes the measurements of currently non-regulated pollutants. Additionally, the ultra-low pollutant emissions are validated on sustainable renewable fuels, which allow to significantly reduce the Well-to-Wheel (WtW) CO_2 emissions. Research is evolving towards reaching zero-impact emissions with this combination.

Demonstrator concept

Base vehicle

The base vehicle of the demonstrator is a Euro 6d C-segment car. The vehicle powertrain consists of a turbocharged 4-cylinder, 1.5 litre gasoline engine with direct injection and a peak power of 110 kW. The engine is equipped with variable valve timing and cylinder deactivation. The powertrain includes a 48 V mild-hybrid system in P0 configuration (belt starter-generator, up to 9 kW as motor, 12 kW as generator). An open engine control unit was available to implement the control measures described below.

Emission control system

The baseline Euro 6d emission control system of the vehicle consists of a 1.67 l close-coupled catalysed gasoline particulate filter (cGPF) and a 0.65 l underfloor three-way catalyst (TWC). Some baseline measurements are done with the system before removing it and replacing by the layouts described below in two additional project phases, 'AECC phase 1' and 'AECC phase 2'. The different systems used are shown in Figure 3 and Table 1.

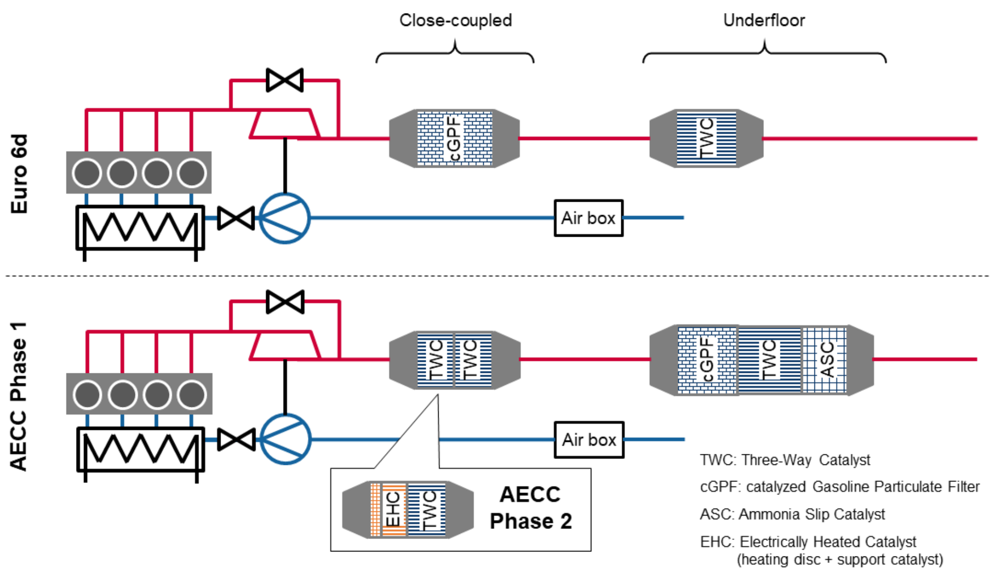

Figure 3 Emission control system layout

In the first project phase, a system is mounted consisting of a close-coupled TWC canning with two equal substrates realizing an overall volume of 1.57 l in combination with an underfloor catalysed 1.64 l GPF, a second 1.1 l TWC and a 0.82 l ammonia slip catalyst (ASC). The most novel aspects of the work are the implementation of an advanced close-coupled TWC substrate and investigation of ASC operation strategy for gasoline vehicles. The two close-coupled cordierite TWC substrates target maximised surface area for enhanced cold-start performance, with 900 cpsi and a wall thickness of 2 mil. NH_3 reduction with the ASC is done in addition to improved lambda control during the catalyst warm-up period. The ASC relies on a combination of storage and oxidation functionality to reduce NH_3-emission. Except for the modifications during the initial warm-up period, with an early closed-loop control to match light-off of the ccTWC, the baseline lambda control approach is used (wide-band sensor before the ccTWC and 2-step lambda sensor behind ccTWC). To further improve catalyst warm-up, a retarded spark timing is used during this phase. Overall, the control strategy aims for zero NOx emissions in steady state conditions after the close-coupled TWC, with minimised emissions of CO and NH_3. Engine bench calibration work is conducted to fine-tune the lambda control strategy to the catalysts implemented. The catalysed GPF is combining high filtration efficiency for particulates with minimised impact on back-pressure and CO_2 emissions. The total TWC volume is spread over three components and targets to control peak engine-out emissions flow. Filter regeneration is done passively.

Table 1 Properties of the emission control systems

	System	Close-coupled	Underfloor #01	Underfloor #02	Underfloor #02
Component	Euro 6d	cGPF	TWC		
	AECC Phase 1	TWC	cGPF	TWC	ASC
	AECC Phase 2	EHC + TWC			
Diameter	Euro 6d	4.66”	4.1”		
	AECC Phase 1	4.66”	5.2”	5.2”	5.2”
	AECC Phase 2				
Length	Euro 6d	6”	4.5”		
	AECC Phase 1	2 x 2.81”	4.72”	3.15”	2.36”
	AECC Phase 2	Heating disc + support catalyst: 2.81” TWC: 2.81”			
Cell density x wall thickness	Euro 6d	300 cpsi x 8 mil	600 cpsi x 2.5 mil		
	AECC Phase 1	900 cpsi x 2 mil	200 cpsi x 8 mil	600 cpsi x 2.5 mil	600 cpsi x 2.5 mil
	AECC Phase 2	Heating disc: 135 cpsi x 2 mil Support catalyst: 800 cpsi x 1.5 mil TWC: 900 cpsi x 2 mil			
Ageing info	Euro 6d	5,000 km within democar			
	AECC Phase 1	Engine bench aged as a system targeting 160,000 km EHC aged separately hydrothermally			
	AECC Phase 2				

In a second project phase, the first substrate of the close-coupled TWC canning is replaced by a metallic substrate equipped with an electrically heated catalyst (EHC) connected to the 48 V system. The total close-coupled TWC volume is kept equal. The EHC consists of a heating disc with 135 cpsi cell density and a support catalyst with 800 cpsi. The lambda control parameters were fine-tuned to the new substrate. In a first step, the EHC is activated 8 s before engine cranking (pre-heating) and kept active until the temperature downstream the close-coupled TWC reaches 370 °C (interrupted temporarily if the heating disc temperature reaches 900 °C), see Figure 4. The vehicle board net allows to apply 4.5 kW heating. Similar temperatures downstream close-coupled TWC are achieved as the end of project phase 1 with this set-up. Secondary air is implemented additionally to improve the heat transfer from the heating disc to the support catalyst during the pre-heating phase. Applying 60 kg/h of secondary air with 8 s of pre-heating increases the temperature at the inlet of the support catalyst with 100 °C at the end of the pre-heating phase, but the light-off of the catalyst is not significantly improved. This indicates the flow distribution over the EHC is not uniform. There was no possibility to improve this within this project. In a final step, 60 s pre-heating are applied, with an external power source as this cannot be realised with the vehicle board net. In this case 6 kW is applied to the EHC. This is to be seen as an outlook to vehicles with a higher degree of electrification, for example a full hybrid or plug-in hybrid. A significant increase in the temperature downstream the close-coupled TWC can be observed with these settings.

The emission control components in project phase 1 are bench aged as a system, targeting 160k km. The EHC that is added is hydrothermally aged as a component as it is added later. Ageing conditions of the two systems are different compared to that of the baseline Euro 6d system which had around 5,000 km accumulated on vehicle. The data is therefore not analysed and compared in detail, but the baseline results are used as a reference to indicate low initial cold-start emissions achieved within this project.

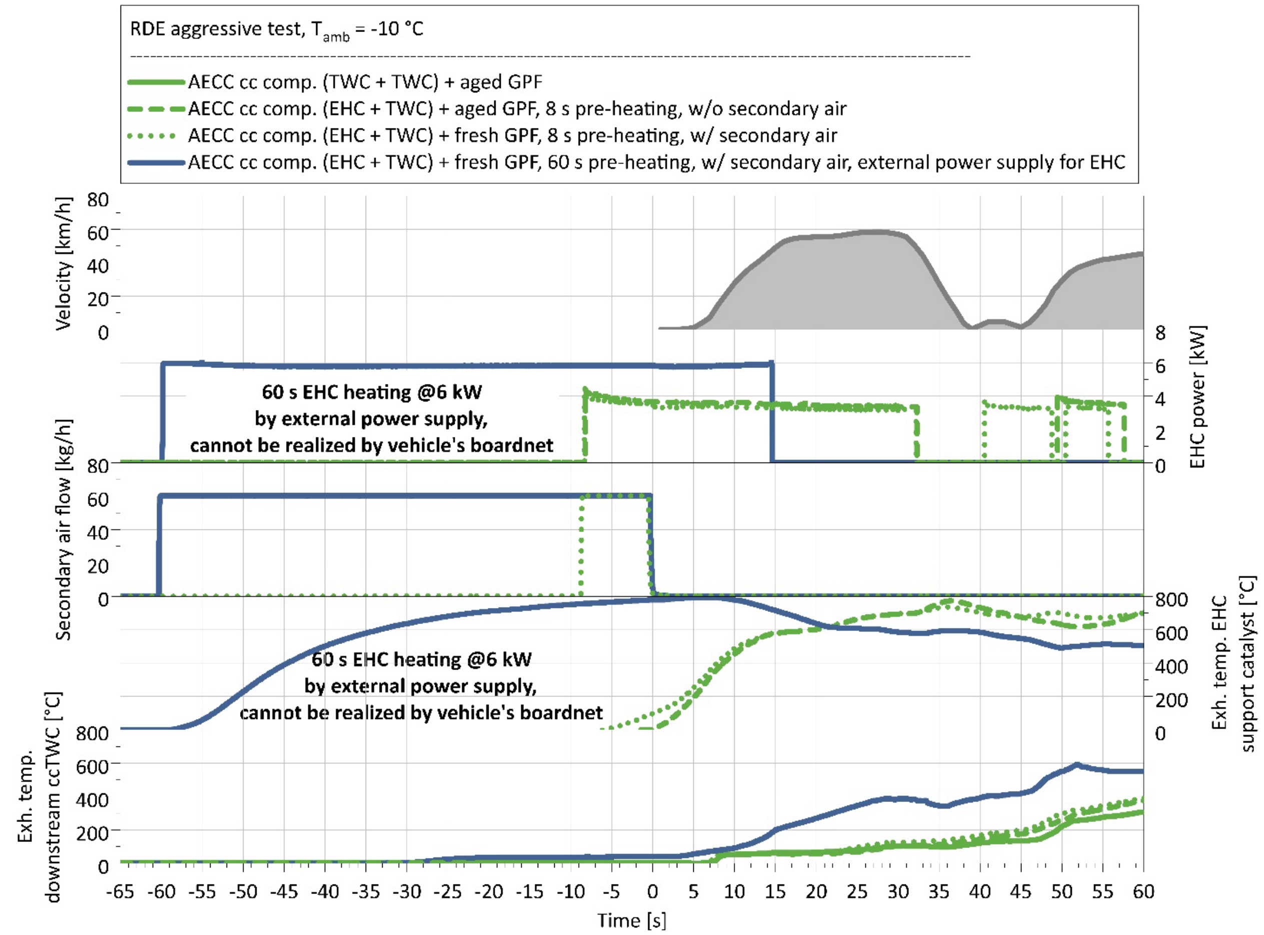

Figure 4 EHC control with pre-heating and post-heating

Fuels

All measurements in project phases 1 and 2 are done on RON95 E10 gasoline fuel. Extra measurements are then done on sustainable renewable fuels to validate the ultra-low pollutant emissions while significantly reducing Well-to-Wheel CO_2 emissions. Blue Gasoline is selected as a fuel which is already available [14], achieving a 20% CO_2 reduction straight from the pump. E-gasoline is also tested as a mid-term available fuel to target 100% renewable content. An overview of fuel properties is given in Table 2.

Sustainable e-gasoline used in this study is a formulated gasoline that replicates physico-chemical characteristics of a fully EN228 compliant gasoline derived from low-carbon methanol (also known as MtG, methanol to gasoline). Today, hydrocarbon production from low-carbon C1 or C2 alcohols is still in a pilot development phase, with a significant potential to be scaled to industrial production in the upcoming decade. Methanol production from CO2 and low-carbon (blue or green) hydrogen is a means of sourcing ultra-low GHG emission feedstock for refineries, and MtG process itself represents an opportunity to revamp existing assets into green refineries. MtG gasoline as formulated in the present work has the potential to be 100% renewable, without using any fossil blend stock for achieving its target properties.

A Well-to-Wheel CO_2 analysis will be conducted according to the JEC (JRC-Eucar-Concawe) methodology v5 [15], but this is not yet available at the time of writing. This will be covered in the presentation.

Table 2 Fuel properties

Fuel property	Units	E10	Blue Gasoline	e-gasoline
Density	kg/m³	742.5	747.7	723.9
RON number	-	96	95	96
Carbon content	%m/m	82.9	82.7	83.0
Hydrogen content	%m/m	13.6	13.5	14.0
Oxygen content	%m/m	3.4	3.6	3.0
Net heating value (m)	MJ/kg	41.8	41.7	41.9

Experimental set-up

Measurement equipment

Tests were done in the lab on the chassis dyno and on the road. On the chassis dyno, three gas sampling points are foreseen before (1) and after (2) the close-coupled TWC, and at the tailpipe (3). Standard gas analysers are foreseen in each position. Fourier Transform InfraRed spectroscopy (FTIR) analysers are used in position 2 and 3. Particulates are measured in the dilution tunnel according to a set-up with a cut-off at 10 nm (PN10). Additional instrumentation is available to monitor temperatures and pressures in between the different components. A Portable Emissions Measurement System (PEMS) is mounted in the vehicle to measure emissions on the road. A prototype PEMS is used that can measure PN10, NH_3 and N_2O in addition to NOx, CO, CO_2, and THC.

Test conditions

A range of on-road and chassis dyno tests are conducted to investigate the emission performance of the vehicle. The ambient and driving conditions covered include conditions within and beyond the Euro 6d RDE boundary conditions. Three types of driving styles are used during on-road tests: smooth, normal, and aggressive. The first two are within the Euro 6d RDE boundary conditions, the aggressive one is outside, see Figure 5. An RDE derived trace is also used for tests on the chassis dyno. This test is aimed to be on the boundary of Euro 6d RDE and is labelled aggressive as well. This test is challenging for the initial cold-start emissions because it is characterized by only a short time between engine start and drive off (4 s) in combination with a first acceleration going up to the maximum allowed velocity of 60 km/h.

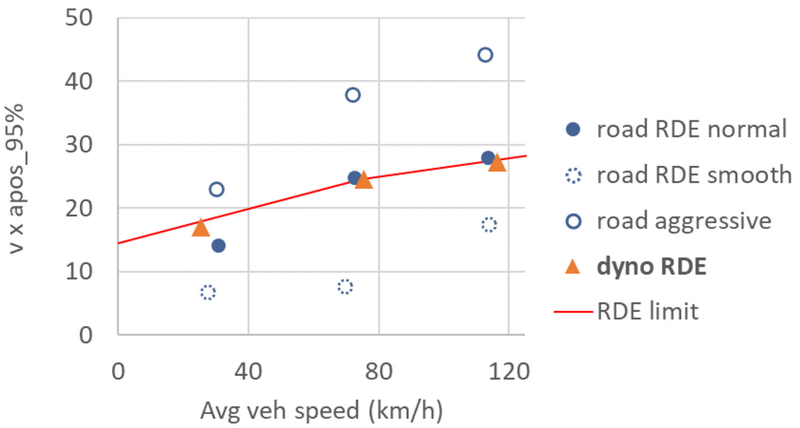

Figure 5 Overview of driving styles used in project

Focus in this paper is on the chassis dyno RDE aggressive test, which is conducted at 23 °C and -10 °C ambient temperature. Tests are always conducted with a cold-start after the vehicle has been soaked at the ambient temperature of the test.

Results and discussion

Pollutant emissions from phase 1

Figure 6 shows the NOx emissions achieved in phase 1 of the project on the RDE aggressive test, at an ambient temperature of 23 °C and -10 °C. A direct comparison with the Euro 6d baseline is not possible, but it is added to provide some reference. A significant reduction is achieved in the initial cold-start NOx emissions despite the additional ageing of the AECC phase 1 emission control system. This is due to the faster activation of the catalytic reactions within the TWC with the 900 cpsi substrate. The results confirm a gasoline vehicle achieves ultra-low emissions under warm operation. For these two conditions, 8 to 16 mg/km is measured over the entire RDE test. Near-zero emissions are achieved within 30 s after engine cranking or 300 m of driving. Absolute initial cold-start NOx emissions at 1 km are 234 mg at 23 °C and 799 mg at -10 °C.

Figure 7 plots the engine-out emissions and conversion efficiency over the close-coupled TWC to understand how to further improve the increase in initial cold-start emissions from 23 °C to -10 °C. The engine-out emissions NOx emissions for both tests is on a comparable level. So, the increase in emissions is due to the around 5 s delay in the light-off of the catalyst at lower ambient temperature. For THC and CO, the engine out emissions increase under the cold conditions as the engine has to be operated more rich to ensure a safe engine start. Moreover, the catalyst heat-up strategy differs from the one at 23 °C, effecting both THC and CO engine out emission. Nevertheless, a retarded light-off also effects the corresponding tailpipe emission levels. Consequently, further work in this project will investigate improvement in the time to reach light-off at -10 °C with the support of active thermal management.

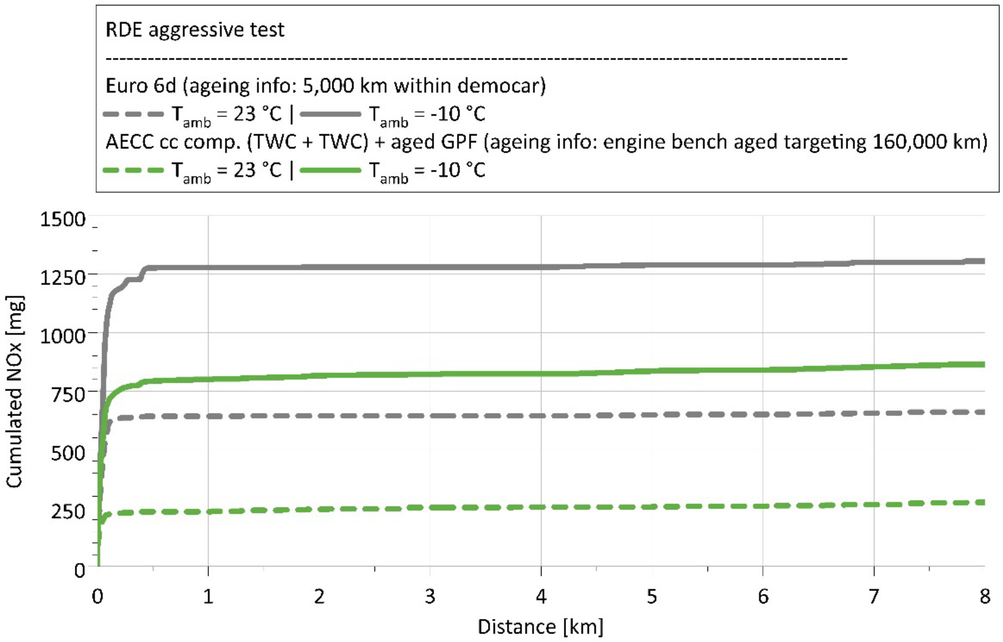

Figure 6 NOx emissions on the RDE aggressive test at 23 and -10 °C

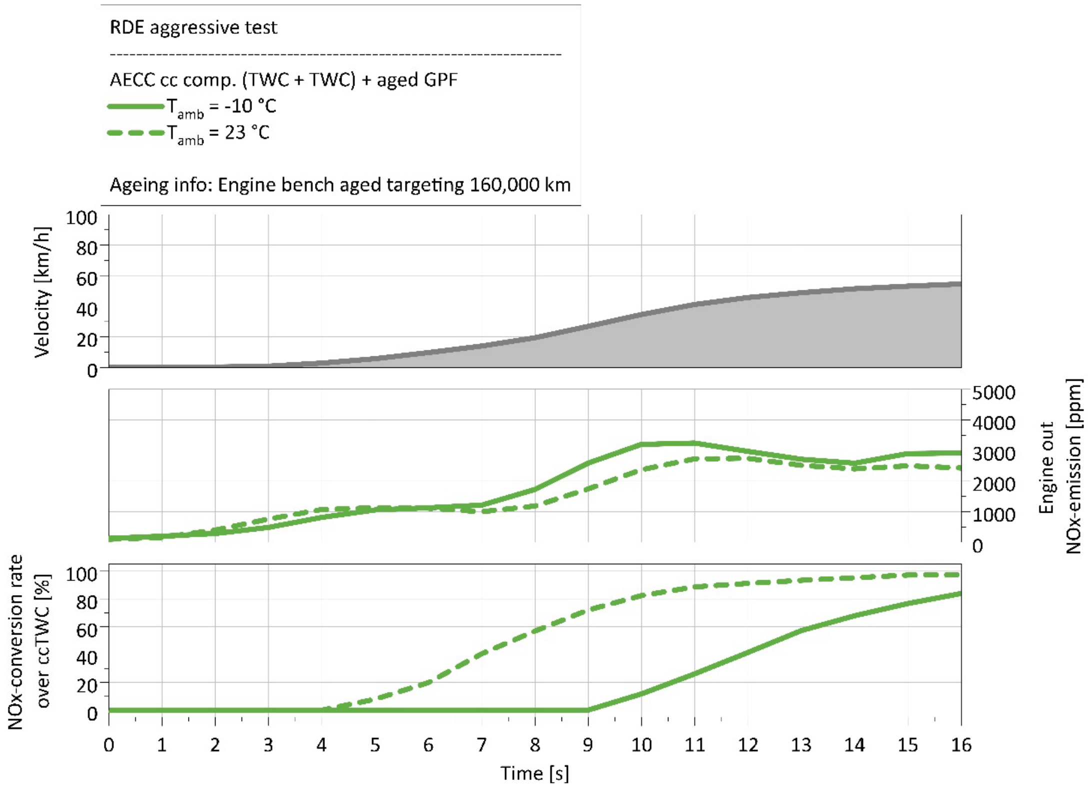

Figure 7 Engine-out NOx emissions and ccTWC conversion rate at 23 °C and -10 °C

The adapted calibration in combination with the ASC supports the reduction of the NH_3 emissions (Figure 8) under availability of oxygen. NH_3 varies between 0.9 mg/km and 3.6 mg/km for the AECC phase 1 emission control system under these test conditions.

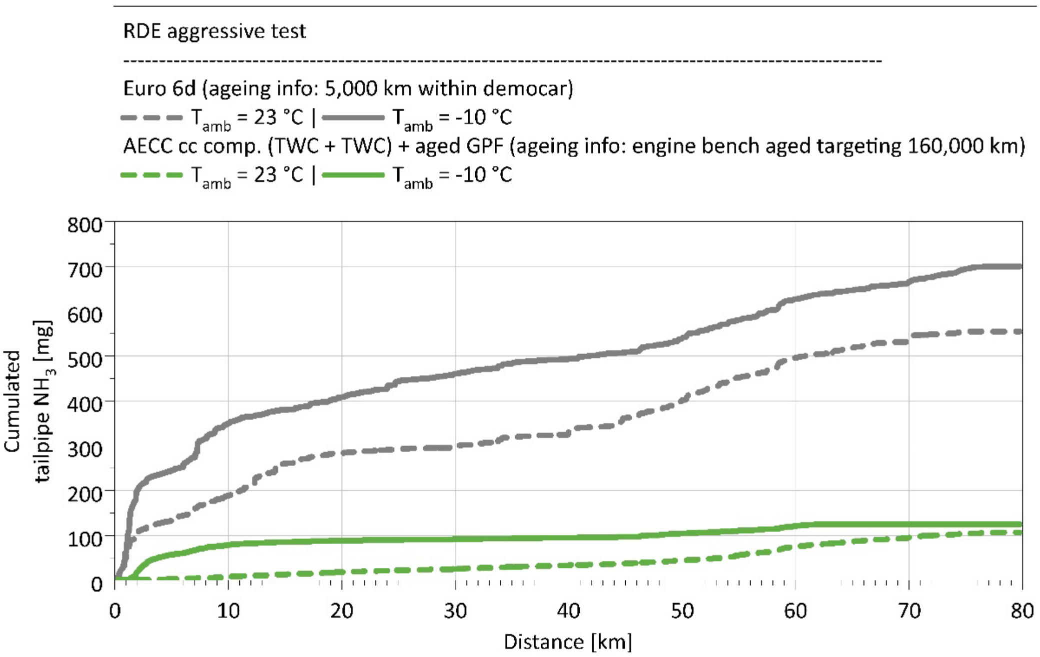

Figure 8 Tailpipe NH_3 emissions on the RDE aggressive test at 23 and -10 °C

More details are available in a previous publication [16], including results of other pollutants.

PN emission with fresh GPF

Ultra-low PN-emission are for example measured in all tests within phase 1, varying between 4.3×10^9 #/km and 4.9×10^{10} #/km. As these results are obtained with an aged system, filtration efficiency is supported by soot and ash accumulation during the ageing of the parts. The RDE aggressive at -10 °C is repeated with a fresh part of the same GPF to get an understanding of the impact.

Figure 9 shows the PN results on the RDE aggressive test at -10 °C for 3 tests measured over the entire project: end of phase 1 (green solid line), start of phase 2 (green dashed line) and end of phase 2 when the fresh GPF is mounted (green dotted line). Results in phase 1 and phase 2 showed that the initial cold-start peak for PN23 and PN10 is very similar, so the PN23 results are representative to investigate the effect of the fresh GPF. Phase 2 results are lower than the phase 1 range mentioned above due to the lack of an initial cold-start peak. It is expected that the reduction in PN for the aged GPF between phase 1 and 2 is due to additional soot or ash accumulation in the filter caused by longer runtime of the component. The impact of the EHC can be excluded as tests without active EHC in phase 2 confirmed the lower PN levels without initial cold-start peak. As expected, the initial cold-start PN peak is higher with the fresh GPF, reaching an absolute value of 4.7×10^{12} particles within the first km. PN emissions of the urban part including the initial cold-start are 2.0×10^{11} #/km, total RDE emissions are 7.2×10^{10} #/km. There is also some PN slip under motorway operation for the fresh GPF.

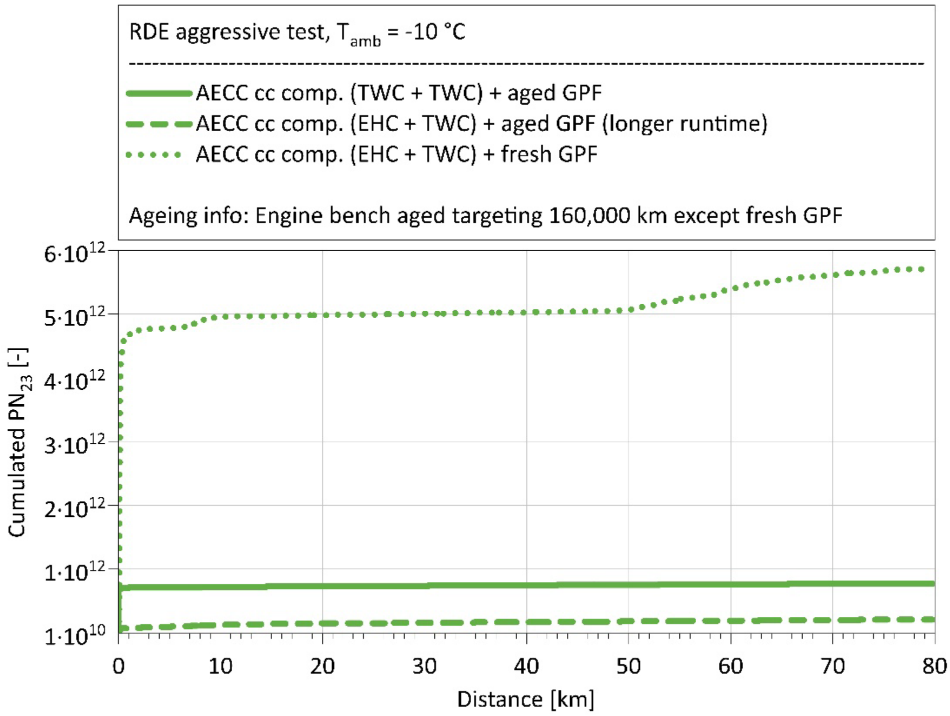

Figure 9 Range of PN emissions on the RDE aggressive at -10 °C

Initial-cold start emissions with EHC and secondary air

Figure 10 shows the cumulative NOx and THC emissions on the RDE aggressive test at an ambient temperature of -10 °C. The Euro 6d and AECC phase 1 NOx emissions were already shown in Figure 6 above. For NOx, similar emissions compared to phase 1 are observed with the application of 8 s pre-heating for the EHC. The initial cold-start NOx peak at 1 km varies between 688 and 753 mg. The urban phase results in 38 and 46 mg/km, the total RDE tests is between 14 and 17 mg/km. Some THC reduction is obtained in the initial cold-start peak at 1 km, from 590 mg with the close-coupled component with two TWC bricksto 387 mg with the close-coupled component consisting of EHC and TWC with 8 s of pre-heating with secondary air. The initial cold-start peak is significantly reduced with the EHC when 60 s of pre-heating is applied with secondary air as an outlook for a full hybrid or plug-in hybrid. The initial cold-start peak at 1 km is then 274 mg for NOx and 178 mg for THC. Corresponding urban RDE results are 22 mg/km NOx and 14 mg/km THC.

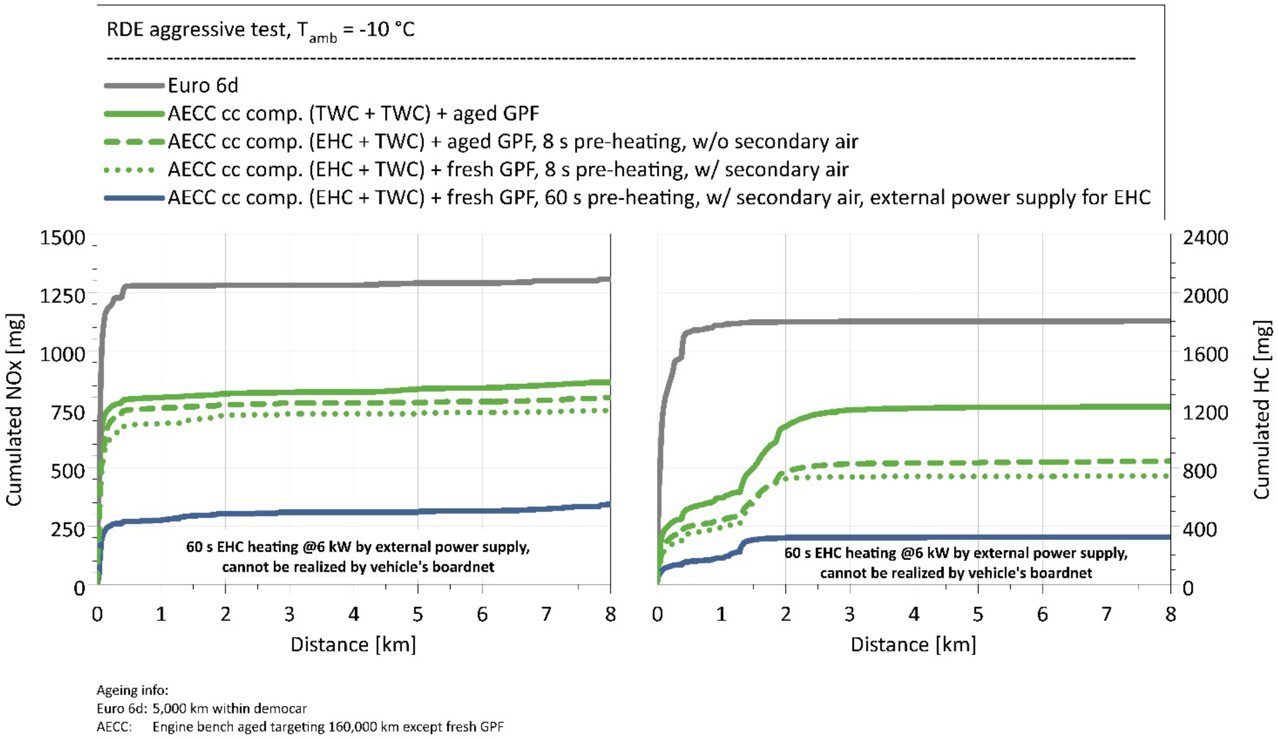

Figure 10 Cumulative NOx and THC emissions on the RDE aggressive test at -10 °C

Validation of pollutant emissions with sustainable renewable fuels

The RDE aggressive test at 23 °C is repeated on Blue Gasoline and e-gasoline and compared to the reference E10 measurements in Figure 11. The results are measured within phase 2 of the project with the EHC active, but without the application of secondary air. Overall similar ultra-low pollutant emissions are measured on Blue Gasoline and e-gasoline, both for the initial cold-start peak and the warm operation.

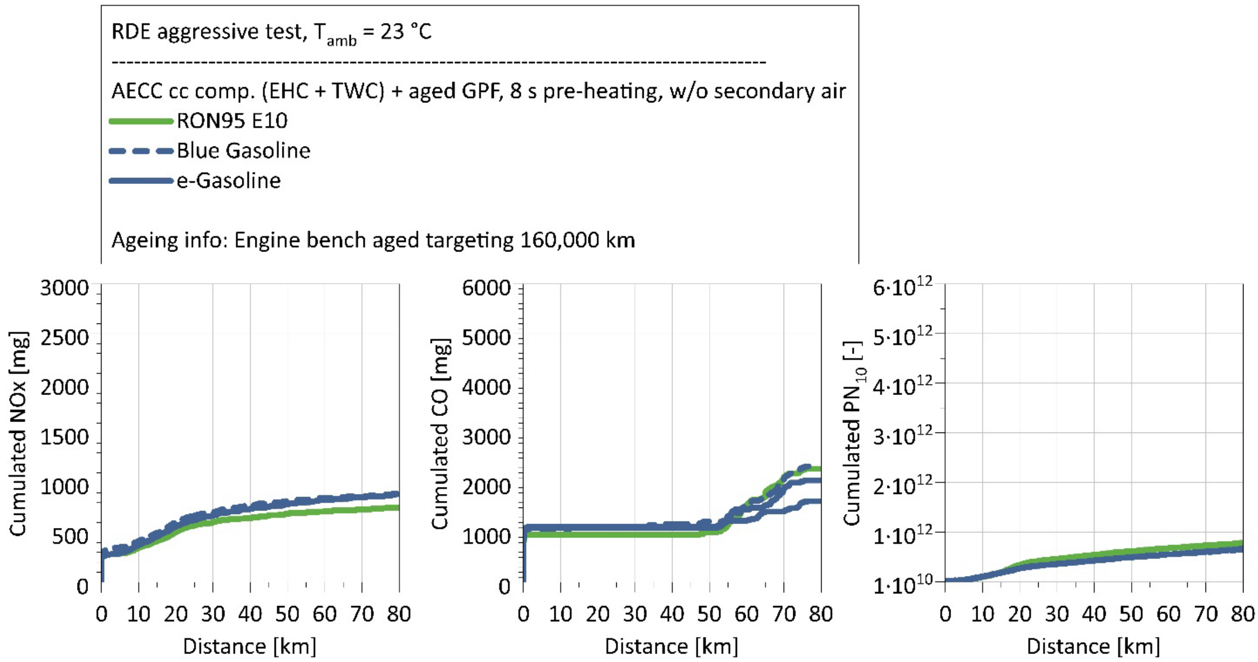

Figure 11 Pollutant emissions of different fuels on the RDE aggressive test at 23 °C

Summary and conclusions

This paper described the implementation of an advanced emission control system on a gasoline demonstrator vehicle equipped with a 48 V mild-hybrid powertrain to indicate further efforts to reduce initial cold-start and non-regulated emissions compared to the already low levels of Euro 6d vehicles. And it described the validation of the ultra-low pollutant emissions on sustainable renewable fuels to show the potential to also reduce the impact of gasoline vehicles on climate change.

Novel aspects for the pollutant emissions control were the application of a close-couple TWC substrate with 900 cpsi and an ammonia slip catalyst in a first phase. In a second phase, an electrically heated catalyst was added with the application of secondary air supply. Ultra-low pollutant emissions were shown on an RDE aggressive test on the chassis dyno at 23 °C and -10 °C. Warm operation emissions are near-zero independent from the ambient temperature. The initial cold-start emissions increase from 23 °C to -10 °C but were significantly reduced compared to the already low Euro 6d base line.

Tests were repeated on two sustainable renewable fuels. Blue Gasoline was selected as an already available fuel, targeting at least 20% CO_2 reduction. E-gasoline is also tested as a mid-term available fuel to target 100% renewable content and distinct WtW CO_2 reduction. It was shown that the ultra-low pollutants measured on reference E10 are confirmed for both sustainable renewable fuels.

Outlook

This paper focused on exploring emissions performance for a combination of low ambient temperature and driving dynamics beyond Euro 6d RDE boundary conditions. It is expected Euro 7 will widen the RDE boundary conditions compared to Euro 6d. Further work might be needed to evaluate the emission control for conditions not covered yet.

Results were obtained with a generic state-of-the-art emission control system applied to a given powertrain configuration. Some hardware and software constraints could not be overcome in this work, for example the shift from ceramic to metallic carrier material for the EHC. Additionally, further technology development is ongoing for the substrate, coating, and active thermal management. Additional aspects need also to be validated to consider series production implementation of the ASC. These are for example:

- OBD/OBM requirements
- NOx and N_2O creation within the ASC
- Durability aspects
- Total NH_3 reduction efficiency under lack of oxygen

Aim is to continue to improve the impact of the combustion engine on air quality.

Further development and validation of sustainable renewable fuels is ongoing for the combustion engine to significantly contribute to reduction in road transport CO_2 emissions, along with electrification of the powertrain and vehicle fleet.

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