Transportation Engineering 9 (2022) 100125

Contents lists available at ScienceDirect

Transportation Engineering

journal homepage: www.sciencedirect.com/journal/transportation-engineering

Future-proof heavy-duty truck achieving ultra-low pollutant emissions with a close-coupled emission control system including active thermal management

Pablo Mendoza Villafuerte [a,*], Joachim Demuynck [a], Dirk Bosteels [a], Thomas Wilkes [b], Volker Mueller [b], Patrick Recker [b]

[a] AECC - Association for Emissions Control by Catalyst aisbl, bd. Auguste Reyers, 80, Brussels B-1030, Belgium
[b] FEV Europe GmbH, Neuenhofstr. 181, Aachen D-52078, Germany

ARTICLE INFO

Keywords:
Heavy-duty
Ultra-low emissions
SCR
Twin dosing
EHC

ABSTRACT

The European Commission is developing legislative proposals for Euro 7 emissions regulations for light- and heavy-duty vehicles. The new regulation will likely focus on ensuring the emissions from heavy-duty vehicles are minimized over extensive on-road operating conditions, in particular urban driving and cold-start operation. The vehicles will need to achieve low secondary emissions like NH_3 and N_2O as well. The paper outlines the ultra-low pollutant emissions achieved by a heavy-duty diesel demonstrator vehicle. The Euro VI long-haul truck is equipped with an innovative layout of state-of-the-art emission control technologies, combined with active thermal management. The new emissions control system integrates a close-coupled DOC including an electrically heated catalyst (EHC), a catalyzed DPF, dual-SCR system - one in a close-coupled position -, with twin AdBlue® dosing controlled by FEV-developed software. Both SCR catalysts contain an ammonia slip catalyst. The innovative system layout allows ultra-low NOx emissions and well controlled secondary emissions in even the most challenging conditions with minimal impact on CO_2 emissions. Pollutant emissions were evaluated over a broad range of operating conditions, the testing was conducted with a single payload of 10% to show the emissions reduction potential.

1. Introduction

Significant efforts have been made in the past decades to reduce pollutant emissions from internal combustion engines. Furthermore, since the implementation of the on-road testing in the legislation, pollutant emissions have been drastically reduced on light and heavy-duty vehicles. Cars and trucks sold today emit significantly lower pollutant emissions than those in 2017. In December 2020, the European Commission adopted the Sustainable and Smart Mobility Strategy (SSMS) [1]. The adopted strategy calls for more to be done: the upcoming proposal for more stringent air pollutant emissions standards for combustion engine vehicles (Euro 7) will ensure that only future-proof low-emission vehicles come to the market.

Further to the SSMS, in July 2021 the European Commission adopted a package of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas (GHG) emissions by at least 55% by 2030, compared to 1990 levels and eventually achieve net-zero GHG emission transport by 2050. They called this package 'Delivering the European Green Deal' [2].

These two packages of regulatory measures have the intention of transitioning to greener European mobility, reducing pollutant and GHG emissions. The different regulations included in these packages pose significant challenges for light- and heavy-duty vehicles which will have to comply with stringent pollutant emission limits as well as demanding reduction of CO_2 emissions.

Heavy-duty vehicles, including trucks and buses, are the backbone of the European economy. These vehicles deliver goods and transport people around the EU's 27 Member States, in towns and cities and thus, it is imperative for them to be as clean as possible. Currently, the HD Euro VI Regulation (EC) No 595/2009 [3] is in force and prescribes emission limits of NOx, CO, PN, PM, NMHC and CH_4 from positive ignition engines (THC in cases of compression ignition engines). The regulation introduced the on-road emissions test using PEMS at type-approval and during in-service conformity (ISC) verifications on

* Corresponding author.
E-mail address: pablo.mendoza-villafuerte@aecc.eu (P. Mendoza Villafuerte).

https://doi.org/10.1016/j.treng.2022.100125
Received 15 February 2022; Received in revised form 31 May 2022; Accepted 1 July 2022
Available online 3 July 2022

trips with a prescribed route (including shares of urban, rural and motorway operations). The ISC test is carried out on public roads and, since the introduction of the Euro VI step E, includes the measurement of cold-start emissions.

The preparatory work for the European Commission's proposal has been conducted within the Advisory Group on Vehicle Emission Standards (AGVES) between October 2019 and April 2021. The CLOVE consortium has presented the different pathways with which current regulated and non-regulated emissions can be measured and considered for compliance. Euro VI vehicles have achieved a progression to lower emissions at urban operation. Latest research confirms an improvement can be seen from Euro VI A to D [4]. Euro VI regulatory evolution has focused on increased representation of urban vehicle operation. Naturally, this has increased the need for technology innovation with improved emissions control under these conditions.

The expected introduction of Euro 7/VII standards is intended to further reduce emissions significantly from heavy-duty vehicles with internal combustion engines in order to improve air quality on the roads and especially in cities. A project was set up to investigate improvement potential in emission control over the full operational window of a truck [5]. The project was divided in two phases. In phase 1, a combination of a newly designed emission control technology system layout and a NOx emissions control system were implemented on an N3 heavy-duty vehicle. The objective was to achieve ultra-low levels of emissions over a wide range of driving conditions. An initial simulation study was conducted to determine the optimal emissions control technology sizing and layout to achieve lowest possible pollutant emissions. The system was calibrated for enhanced NOx conversion finding an optimized AdBlue® dosing profile to achieve lowest emissions of NH_3 and N_2O. The results of phase 1 of the project have been published and are available for consultation [5–7] This paper `s the results of phase 2, which was an extension to the original project and looks into even further reduction in the initial cold-start emissions by the use of active thermal management. Previous publications have found that active thermal management systems can achieve substantial reductions during the heat-up phase of the catalysts [8,9], unfortunately there are limited publications currently available studying these technologies. An Electrically Heated Catalyst (EHC) was installed in the close-coupled diesel oxidation catalyst position in the current work. The investigation particularly looks into its effect on the cold emission phase of different on-road tests.

2. Project setup

2.1. Vehicle and powertrain characteristics

The heavy-duty vehicle used in the project is an N3 Daimler Actros 1845 LS 4x2 tractor equipped with a 12.8 l engine with high pressure EGR and homologated to Euro VI-C. The rated power of the engine is 330 kW at 1600 rpm and the type approval reference work in the WHTC is 29.4 kWh.

2.2. Emission control system layout

For phase 1 and 2 of the project, simulation studies were conducted using FEV's SimEx software. For phase 2, the study evaluated the impact of implementing the active thermal management based on an electrically heated catalyst. The simulation studied the implementation of an EHC in the close-coupled Diesel Oxidation Catalyst (DOC) position to analyse the required EHC power level to heat up the close-coupled Selective Catalytic Reduction (SCR) catalyst in a shorter time, and thus, further reduce cold-start emissions. The engine-out quantities from previous measurement campaigns [5–7] were imposed as inputs to the simulation environment consisting of the exhaust aftertreatment system model and control functions. Several EHC power levels were simulated including 5, 10 and 15kW. The EHC controller was simulated based on the outlet temperature of the close-coupled SCR, which was set to 220°C. The simulated results showed the reduction in NOx emissions during urban and an alternative low load route, of which the urban delivery simulated results are shown in Fig. 1. The final decision on the power to be used was based on the energy consumption and the NOx reductions possible to be achieved. This required the EHC to have a maximum power of 12kW.

The main conclusion from the simulation study was that the integration of the EHC in the close-coupled DOC position significantly improves the NOx reduction efficiency in all investigated routes, especially within the cold-start and long idling phases.

2.3. Emission control system

Previous publications have described in detail the phase 1 system implemented in the AECC heavy-duty demo vehicle [5–7]. The innovative emission control system is composed of a close-coupled (cc) DOC, SCR and ammonia slip catalyst (ASC). The ccSCR/ASC is placed as the first component in the boxed system followed by a DOC, catalysed Diesel Particulate Filter (cDPF) and SCR/ASC, with twin AdBlue® injection and a hydrocarbon (HC) doser to support DPF regeneration.

The ccDOC is fitted directly behind the turbine for fast CO and HC control, and allows optimal heat transfer into the emissions control system. This DOC consists of two substrates. Based on the results of the simulation study, for phase 2 the EHC was placed as a first substrate of this component as can be seen in Fig. 2.

A novel twin AdBlue® dosing system was implemented to the demonstrator truck and controlled using FEV's in house developed twin dosing control software. The software controls both injection systems individually and coordinates the AdBlue® dosing. The system determines if the front or rear system should be used to optimize conversion efficiency.

During the system integration it was decided to instrument the EHC with 14 thermocouples to monitor the temperatures throughout the component. Such setup ensures that the maximum EHC temperature (which depends also on flow distribution) is recorded and controlled. The amount of power needed to heat up the system was defined by exhaust mass flow and different temperatures in the emission control system. Exhaust mass flow and upstream temperature define the maximum EHC power limit, which was additionally ramped down based on monitored temperatures behind EHC to avoid too high EHC surface temperatures and to protect the component.

To be able to use the EHC effectively and to apply the power required as long as needed, the vehicle was fitted with an external 48 V system. This was provided by an external GenSet powerful enough to supply the required power. This device was not connected in any way to the engine of the vehicle and the additional load did not impact the engine operation. The AC/DC converter installed in the vehicle supplied 10.8 kW maximum power, which defined the EHC capacity. A laboratory controller provided by the EHC supplier was used for pulse with modulation (PWM) control of the EHC. At idle, EHC performance in the HD demonstrator truck is capable of achieving average gas temperatures downstream of the EHC between 350 and 400 °C and temperatures upstream of the ccSCR > 200 °C.

The EHC was calibrated based on the simulation work described in section 2.2. The in-vehicle calibration of the system was based on a defined ccSCR setpoint allowing sufficient NOx conversion and acceptable electric energy consumption. Special focus on cold-start as well as transition to urban driving and long idle phases were the targeted conditions to fine tune the EHC calibration. Reference tests without EHC activation and the same idle time before driving start were conducted for direct comparison of temperatures and final validation of results was conducted with a dedicated PEMS campaign.

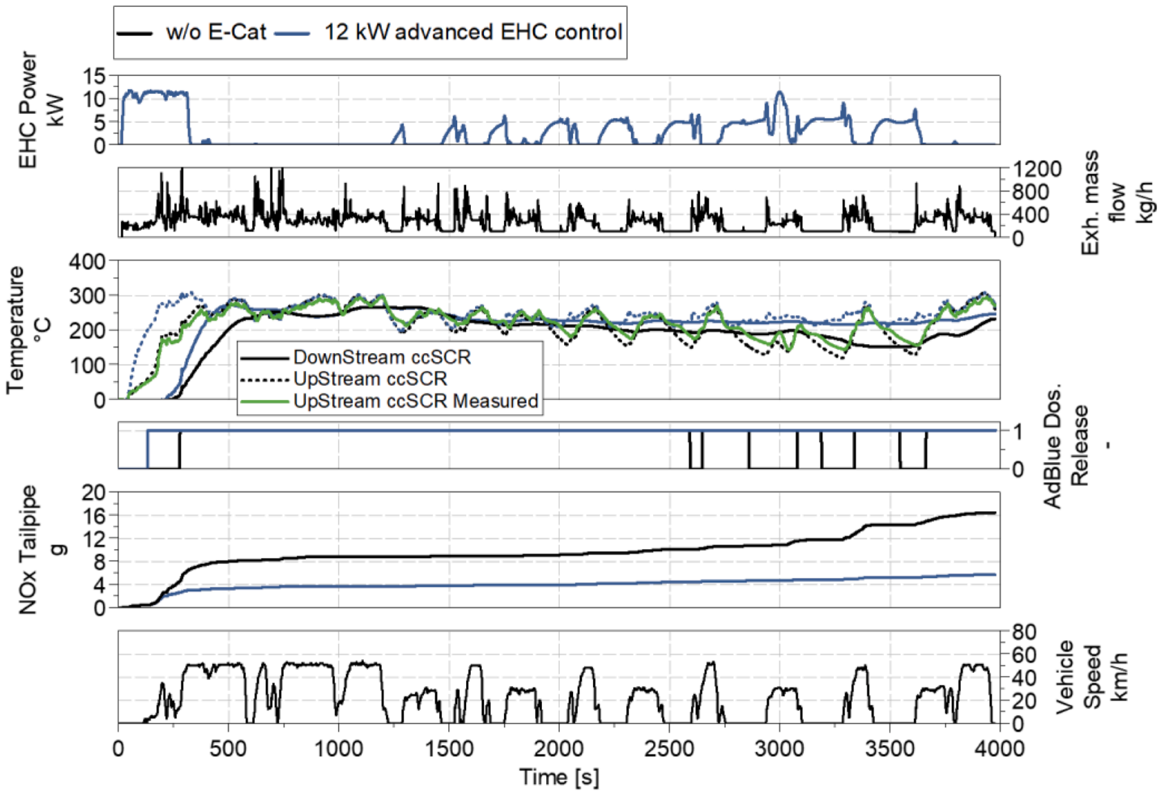

Fig. 1. Final EHC control functions simulation based on a close-coupled SCR target temperature of 220°C.

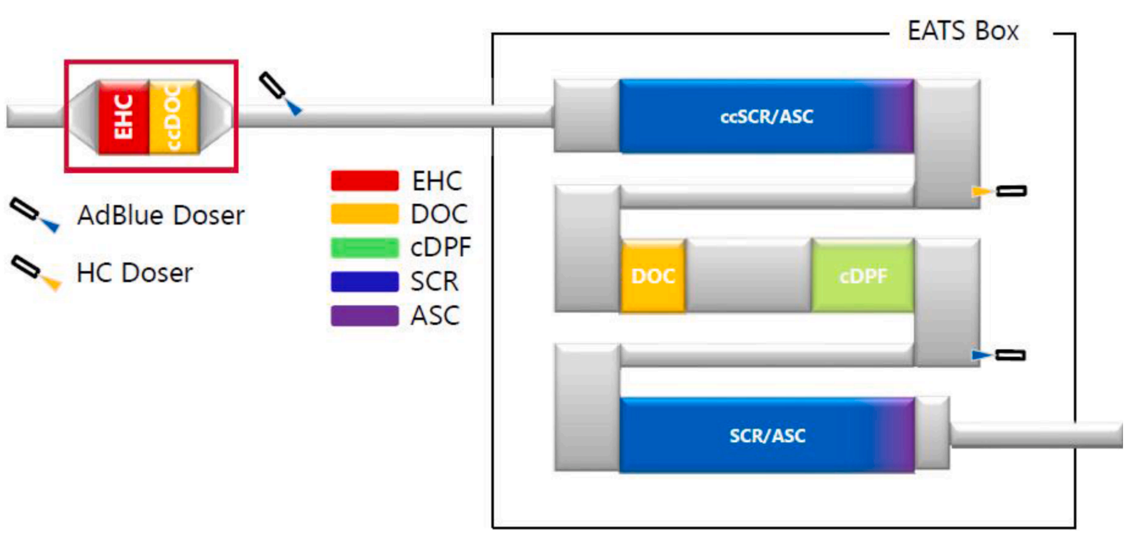

Fig. 2. Final system layout.

2.4. PEMS equipment integration

The emission results include tests performed with Portable Emissions Measurement System (PEMS). To fully quantify both cold-start NOx emissions and secondary emissions compliance, an enhanced AIP PEMS was fitted to the demonstrator vehicle as shown in Fig. 3. The tailpipe was modified to contain the Exhaust Flow Meter (EFM) for the PEMS kit and the equipment itself was set up in the trailer bed. A 4-inch diameter exhaust flow meter was used in the installation as well as 4.5 m heated exhaust line. High capacity batteries were used to power the PEMS as these ensured long testing time.

The PEMS kit contained NO (Chemiluminescence Detector) and NO_2 (Photoacoustic spectroscopy) analysers to determine tailpipe NOx speciation, as well as CO and CO_2 measurement devices (Non-Dispersive Infrared Sensor). In addition to the gaseous measurements, PN10 measurement equipment was also fitted. NO is measured using chemiluminescence spectroscopy. NO_2 was measured using photo acoustic sensor technology. CO and CO_2 were measured using Non-dispersive Infrared Spectroscopy (NDIR) and the PN10 was measured using a condensing particle counter (CPC). There were no intermediate PEMS emission measurements points. The intermediate measurements for NOx and NH3 were possible through dedicated sensors.

In addition to the standard equipment, the truck was fitted with both portable NH_3 and N_2O measurement technology. N_2O was measured

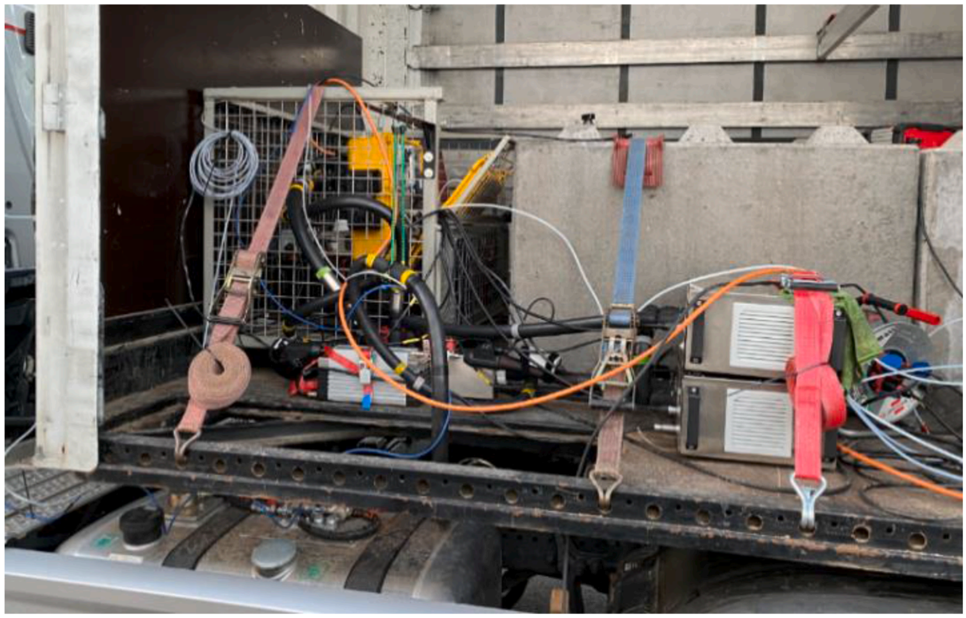

Fig. 3. PEMS installed in the vehicle.

using a Non-Dispersive Infrared Sensor and the NH_3 was measured using a Quantum Cascade Laser setup.

3. On-road tests

The tests were defined to verify the broad range of driving conditions covered in the base project [5–7]. These routes covered a typical in-service conformity route as well as two urban delivery routes (one with extended stops). The tests covered a significant range of the operating map of the engine. All tests were conducted at 10% payload.

The in-service conformity and urban delivery (also with extended stops) routes speed profiles are meant to replicate typical missions of the vehicle and can be seen in Fig. 4 below. The in-service conformity route is compliant with current Euro VI regulation (EU(582/2011)) and it includes shares of operations prescribed for an N3 vehicle. The average speed during urban operation was 30 km/h, in rural 55 km/h and on the motorway 80 km/h. The urban delivery route has a maximum speed of 50 km/h and an average speed of 21 km/h. The urban delivery route

Fig. 4. Speed profiles of the different routes completed

with extended stops follows the same route and its average speed is lower, 15 km/h. All the on-road testing was conducted on public roads in the Aachen area in Germany.

The routes ensure a broad coverage of the engine operating map as can be seen in Fig. 5. The ISC test ensures a complete operation of the engine torque, including full load operation. The urban delivery routes cover lower load operation compared to the ISC as it contains continuous 1, 2- and 3-min stops where the engine is kept idling. The urban delivery route with extended stops follows a similar route but the stops are longer, varying between 2, 4 and 6 min.

During the campaign, all tests were conducted with the vehicle preconditioned. Such preconditioning included running the vehicle at constant speed with high engine load to prepare the vehicle for the next day of testing. The details of the preconditioning are shown in Fig. 6. This protocol was implemented to investigate severe conditions for the emission control system. The preconditioning depletes both SCR's ammonia storage as well as passively regenerates the diesel particulate filter. Consequently, testing under cold ambient conditions would show the challenge for the system to perform efficiently in a short time after engine start. Furthermore, the preconditioning allows for testing of the vehicle in comparable starting conditions, and this is important to compare the test results.

4. Results

The test evaluation shows the benefits achieved with this system. It must be noted that all results are reported as measured and do not consider any additional post processing or error margins.

4.1. NOx emissions

4.1.1. General overview

Fig. 7 shows the summary of NOx emission results obtained during the different testing campaigns completed by the AECC HD diesel demo vehicle and reported in previous publications for phase 1 [5–7]. Additional results have been added to the figure showing the latest PEMS-based NOx measurements from the testing of the vehicle with active thermal control.

Previous results show urban operation emissions from urban delivery and in-service conformity testing, conducted within a broad range of temperatures from 4 to 23°C with an empty and a normally loaded SCR. The on-road NOx emissions results with normal SCR loading are between 42 and 208 mg/kWh. For these tests, no preconditioning was conducted and the urea loading in the system at the beginning of the trip is how it remained at the end of testing on the previous day. On the other hand, results of on-road testing with empty SCR at the beginning of the trip show a higher range of emissions, varying from 168 to 475 mg/kWh. This range represents testing the vehicle with a cold engine with both SCRs' storage depleted of urea. After the system is warm, near-zero emissions are measured during rural and motorway operation.

Fig. 7 also includes the NOx results achieved after implementing the active thermal management achieved by installing the electrically heated catalyst. These tests, described in section 3, were conducted with empty SCRs at the beginning of the trip and within an ambient temperature of 5 to 8°C. The resulting urban NOx emissions vary from 88 to 112 mg/kWh during urban operation. These emissions are lower than the lowest result from previous testing with empty SCR tests.

4.1.2. Detailed effect of the implemented active thermal management

Testing with the support of the electrically heated catalyst delivers a significant decrease of cold-start emissions regardless of the trip conducted.

Fig. 8 below shows the comparison between an urban delivery test with and without EHC during the first 600 s of operation. The test with the EHC results is represented by solid lines. The temperatures upstream of the ccSCR and the box SCR are plotted. As can be seen, when using the EHC, the ccSCR reaches ~200°C in a shorter period (~60s). The ccSCR layout is already allowing the system to heat up quickly but with the EHC addition, the heat-up period is further decreased. The figure shows the release of the AdBlue® and further down the NOx emissions downstream of the ccSCR can be seen, as well as the NOx in the tailpipe. Further to these, the figure includes the power required by the EHC to heat the system up in these initial 600s, as well as the exhaust mass flow passing through the pipes which will influence the heat required.

In the urban driving route, the use of the EHC and the NOx storage effect resulted in ~70% tailpipe NOx reductions during the first 600s, and 67% reduction in the whole trip compared to a similar test conducted without EHC. A similar result is found on the extended urban delivery test, where a reduction of ~80% was achieved. On the urban delivery test with extended stops another benefit of the EHC can be seen in Fig. 9. This is the impact of the EHC in keeping the ccSCR within the target temperature during extended stops of 2, 4 and 6 min. The emission slip which occurred at the tailpipe during the first acceleration after these stops without EHC (at around 2000s, 2750s, 3400s and 3600s) is no longer present with EHC.

It is important to note that the NOx concentration profiles show a delay in respect to the start of the initial cold-start peak. This is attributed to NOx absorption in the water inside the SCR, which desorbs at the point the SCR reaches its operating temperature, generating the initial NOx emissions peak. This effect has been discussed and studied [7, 10, 11].

The in-service conformity test posed a different working condition for the EHC. The ISC trip is characterized by including shares of operation starting with urban, rural and motorway. The test started with a cold engine and the EHC was activated throughout the test. However, as the system reached working temperature during the urban operation,

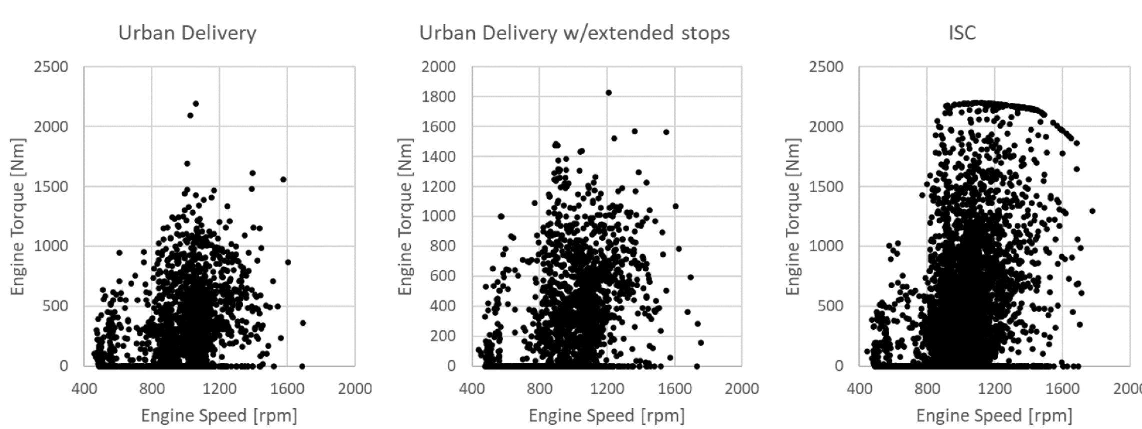

Fig. 5. Operating engine map covered by the different routes completed.

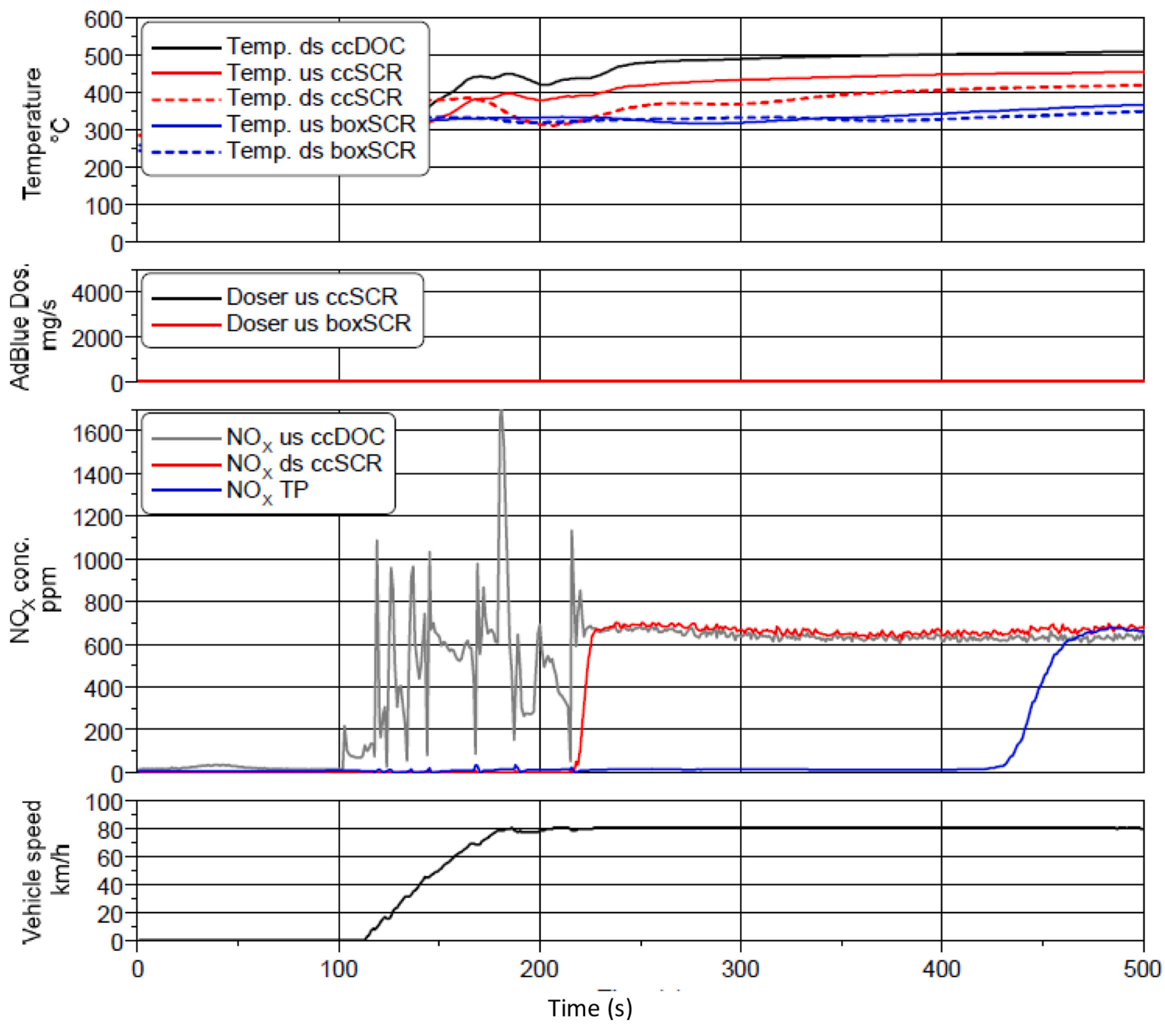

Fig. 6. Preconditioning protocol implemented to deplete ammonia storage in both SCRs and passively regenerate the DPF.

the EHC was not required to intervene as the operating regime of the engine/vehicle kept the system at regime temperature. As can be seen in Fig. 10, the dosing release was advanced ~108s and emissions were reduced by 80% within the first 600s. This was also achieved in conjunction with high NOx storage desorption effect in this test.

4.2. Ammonia (NH3) and nitrous oxide (N_2O) emissions

Fig. 11 shows NH_3 emissions measured on the reported phase 2 tests. In the case of the ammonia, the results are very low and there is no additional value in comparing these to previous tests. On the other hand, the Fig. 12 shows a summary of the N_2O emissions. Results with and without EHC are within the same level as previous reported.

Ammonia emissions can be generated by an overdose of AdBlue®, however the system is equipped with ammonia slip catalysts after each SCR. As can be seen, the ammonia reported by the PEMS is near to zero. The results from this campaign confirm previously reported [5–7] ultra-low NH_3 emissions from this vehicle. During the tests conducted, the ammonia results have shown an excellent slip control from the emissions control system. Overall, the NH_3 emissions measured in every condition have been extremely low.

Fig. 12 shows a summary of the N_2O emissions of the tests with and without EHC. N_2O formation can be related to the occurrence of unselective catalytic reactions, which can occur within the DOC or even the ASC via unselective oxidation of unreacted NH_3. The production of N_2O throughout the trips is in line with what has been reported in previous publications of the performance of this truck. Previous results show urban operation N_2O emissions with normal SCR loading are between 58 and 78 mg/kWh. With empty SCR at the beginning of the trip the N_2O emissions vary from 18 to 60 mg/kWh. Results show N_2O emissions from the phase 2 testing (with empty SCR and regenerated DPF) varying from 65 to 87 mg/kWh.

During rural operation on-road testing of phase 1 with normal SCR loading, the results vary from 42 to 68 mg/kWh and from 19 to 37 with empty SCR. The phase 2 system single ISC result in rural operation is 25 mg/kWh. Within the motorway operation, phase 1 on-road testing with normal SCR loading results in N_2O emissions varying from 27 to 40mg/kWh and from 16 to 58 mg/kWh with empty SCR. Phase 2 system results under motorway operation are 47 mg/kWh.

The three routes show a similar level of N_2O as analogue tests completed without the EHC activated. This means the EHC implementation had no significant effect on the production of this greenhouse gas.

4.3. Particulate number (PN10) results

A summary of the particulate number (PN10) results obtained during phase 1 and 2 tests are presented in Fig. 13. The particulate emissions have been measured by the PEMS installed on the vehicle. This instrument has been described in section 0. The particulate number is reported as measured without considering any measurement uncertainty. Crankcase emissions have not been considered in the results.

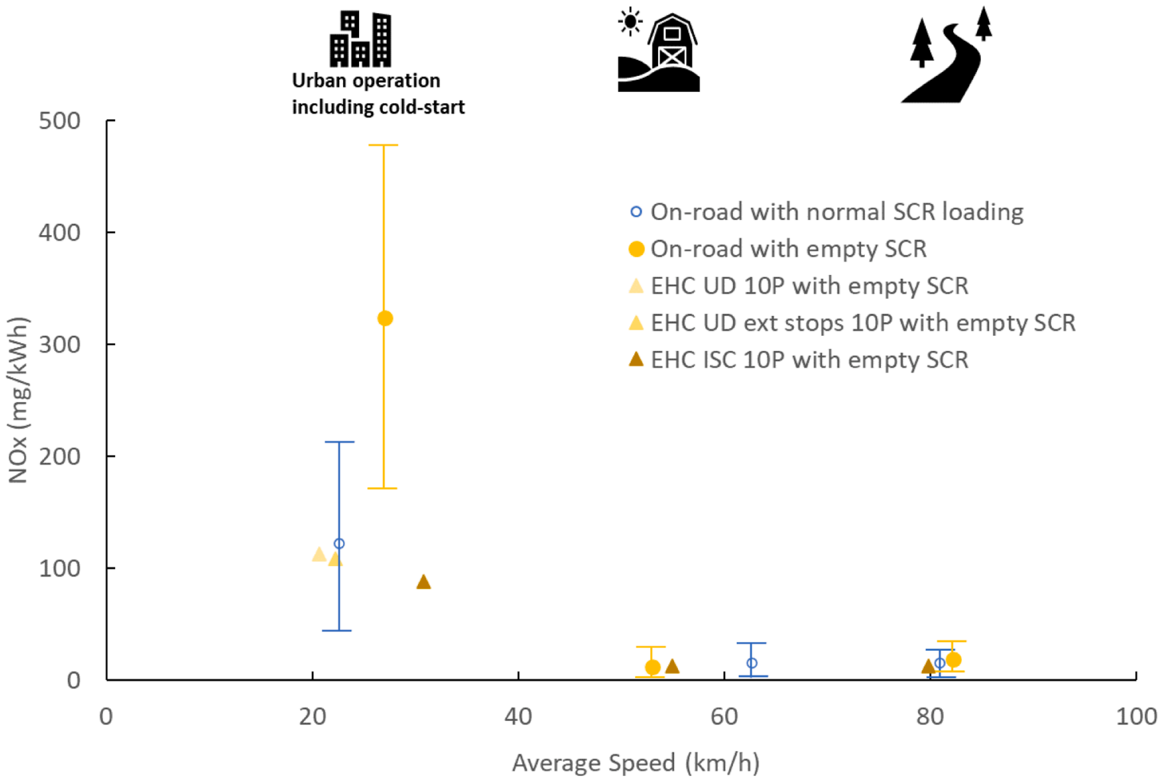

Fig. 7. Summary of NOx emissions obtained throughout the AECC HD diesel vehicle project, including latest results using electrically heated catalyst with an empty SCR at the beginning of the trip.

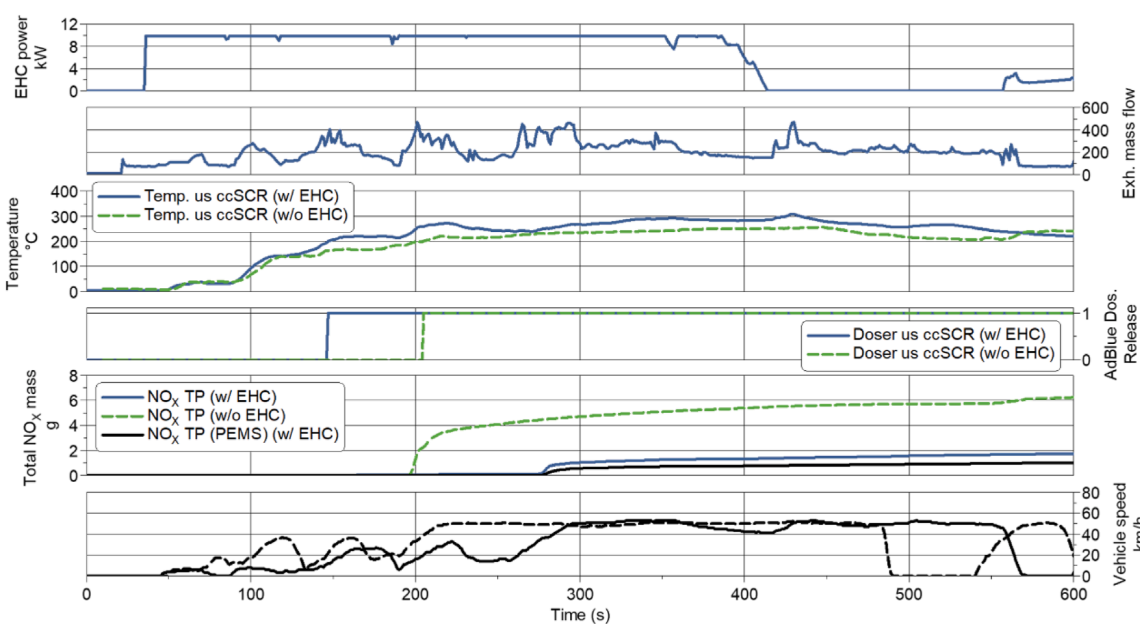

Fig. 8. Initial 600 seconds of the Urban delivery route NOx emissions.

All tests were conducted with a preconditioning of the emission control system that, besides depleting the SCR from urea, was designed to achieve high combustion temperatures to allow passive regeneration within the cDPF. It is, however, very difficult to achieve the same condition of the filter at the beginning of each test. Fig. 13 shows the PN10 emissions are found mainly during the cold-start phase. Compared to previously reported results, tests have produced fewer PN emissions during cold start than the analogue tests without EHC, although limited data is available to further investigate how much of the improvement can be attributed to the EHC.

Results from phase 1 show PN10 emissions from urban operation with normal SCR loading are between 6.07×10^{10} to 1.38×10^{11} #/kWh. With empty SCR at the beginning of the trip the PN10 emissions vary from 1.74×10^{11} to 4.16×10^{11} #/kWh. Results show PN10 emissions from the phase 2 testing (with empty SCR and regenerated DPF) varying from 2.38×10^{10} to 1.34×10^{11} #/kWh.

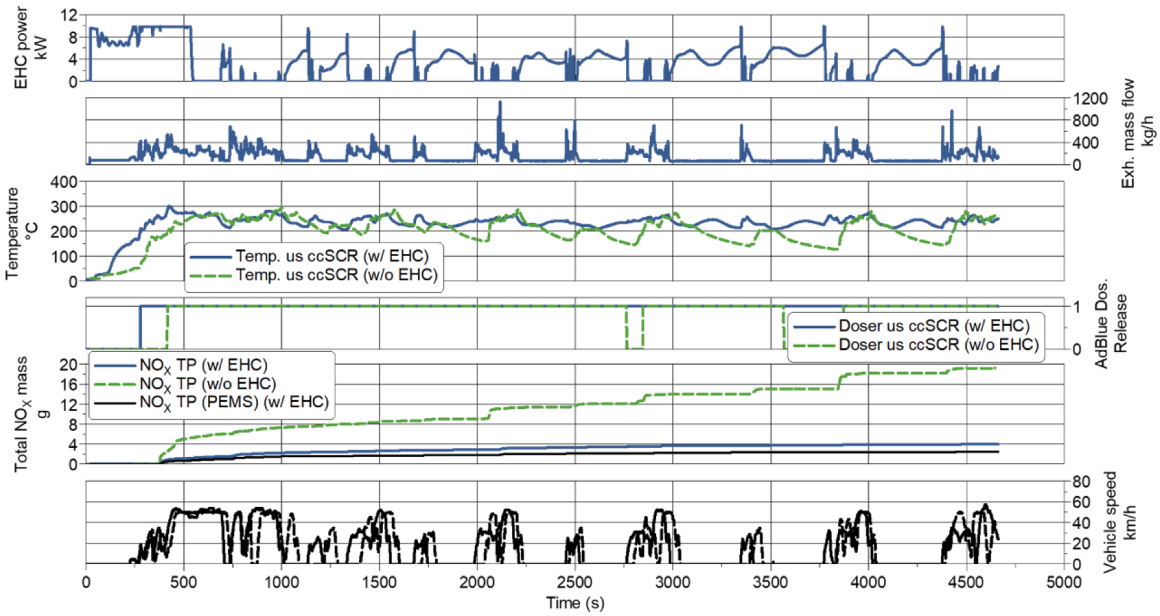

Fig. 9. Effect of EHC operation on keeping the ccSCR within the target temperature of 220 °C within an urban delivery trip.

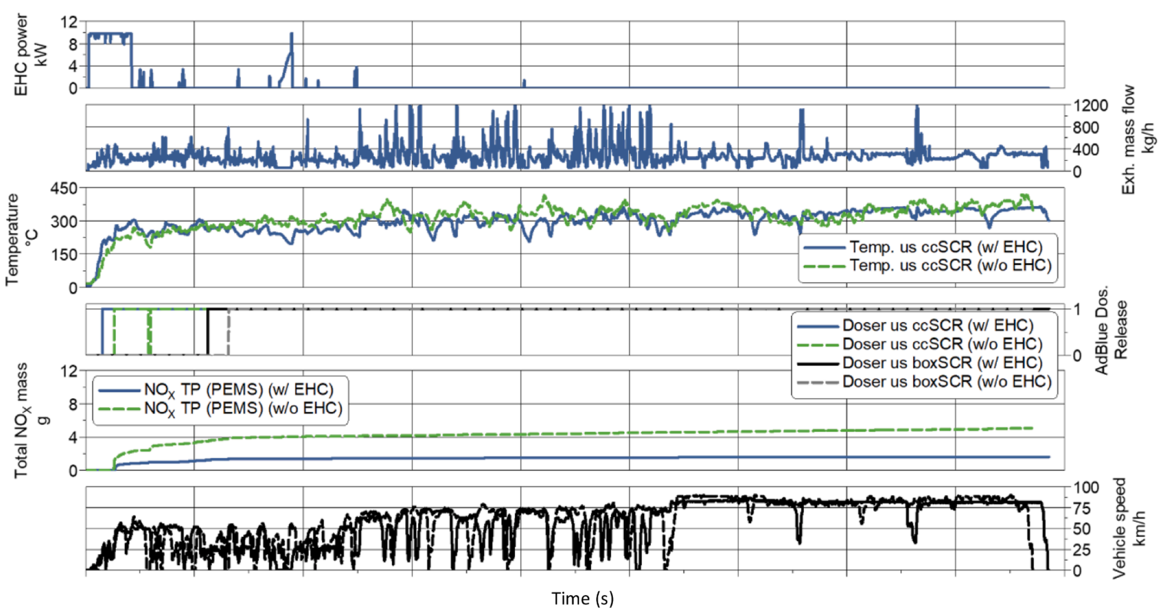

Fig. 10. ISC route NOx emissions.

During rural operation on-road testing of phase 1 with normal SCR loading the results vary from $2{,}46x10^{9}$ to $7{,}94x10^{9}$ #/kWh and $4{,}36x10^{10}$ to $6{,}15x10^{10}$ #/mg/kWh with empty SCR. The phase 2 system single ISC result in rural operation is $3{,}78x10^{10}$ #/kWh. Within the motorway operation, phase 1 on-road testing with normal SCR loading results in PN10 emissions varying from $2{,}26x10^{9}$ to $6{,}43x10^{9}$ #/kWh, and from $3{,}99x10^{10}$ to $5{,}14x10^{10}$ #/kWh with empty SCR. The phase 2 system under motorway operation results in emissions of $4{,}60x10^{10}$ #/kWh.

4.4. Fuel consumption

As presented in section 2.3, the integration of the EHC included the implementation of a 48 V external system to provide the power needed by the EHC to work, meaning that the power used by the EHC was measured externally. To calculate the impact on fuel consumption it was necessary to calculate this power back to fuel consumed and add to the final fuel consumption of the test. The energy used by the EHC varied from the test where the EHC intervened the least, the ISC, to the test where it was used the most, the urban delivery with extended stops. The energy consumption varied between 1.03 (ISC) and 4.2 (urban delivery) kWh respectively. The calculated additional fuel consumption based on the energy consumption depends on distance, for example, for the ISC is 1%.

The reported calculated additional fuel consumption is not representative of a future implemented 48V board net in a heavy-duty vehicle with smart energy management, where benefits of energy recuperation and engine load point shift can be used. For this reason, the values reported above are for reference only.

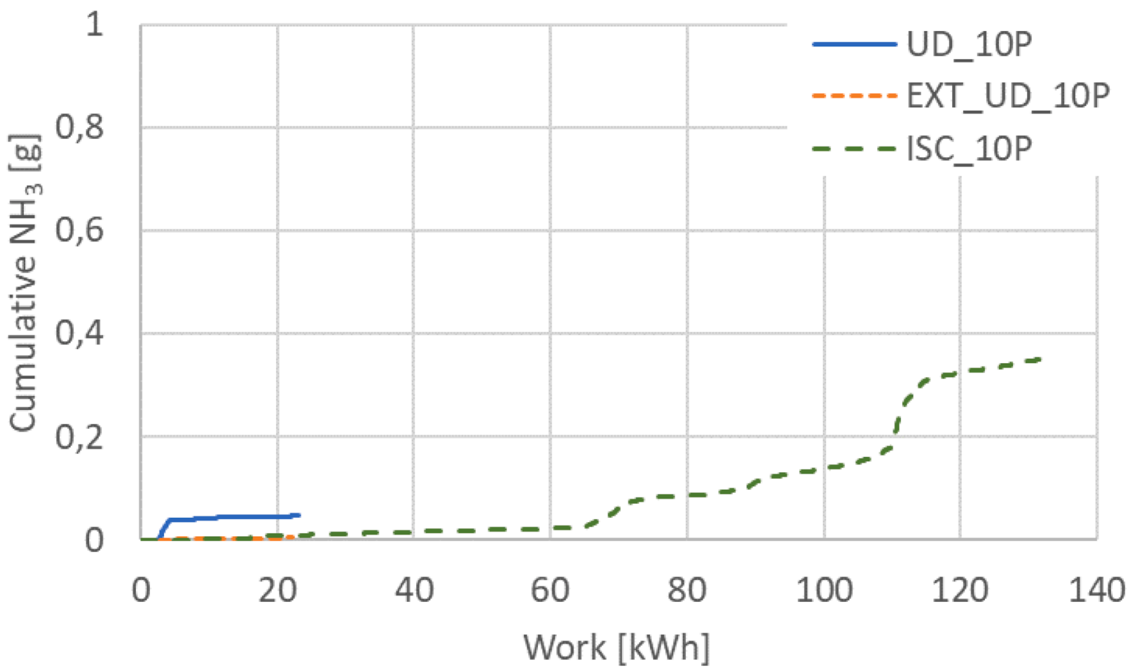

Fig. 11. NH3 emissions of urban delivery, urban delivery with extended stops and in-service conformity routes.

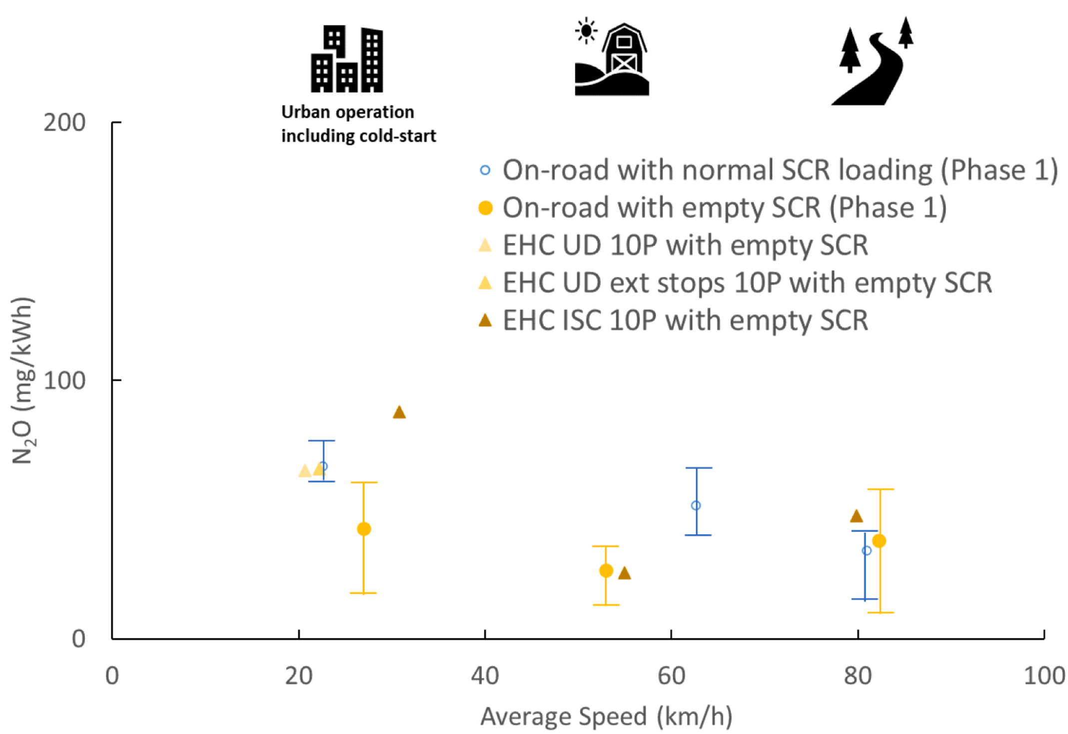

Fig. 12. Summary of N2O emissions of urban delivery, urban delivery with extended stops and in-service conformity routes.

5. Conclusions

This work summarized the emissions performance of an advanced demonstrator N3 vehicle with a state-of-the-art emission control system including active thermal management. The vehicle was tested on the road to investigate the further emissions reductions possible through the implementation of an electrically heated catalyst in an already efficient emission control demonstrator system [5–7].

The enhanced emission control system achieves activation temperature for the ccSCR more quickly with the help of the EHC. Temperatures downstream of the ccDOC, upstream and inside the ccSCR can be increased up by 50-100°C during cold-start compared to a system without EHC. The faster heat-up of ccSCR with EHC advances the release of the first AdBlue® doser. During the normal and extended stops, the EHC intervenes if the temperature falls below the assigned threshold, and thus maintains the ccSCR above 220°C.

The contribution of the EHC substantially reduced the cold-start emissions. The use of the active thermal management preserves the emission control temperature during short and long stops, avoiding any NOx slippage. The emissions control system was preconditioned before

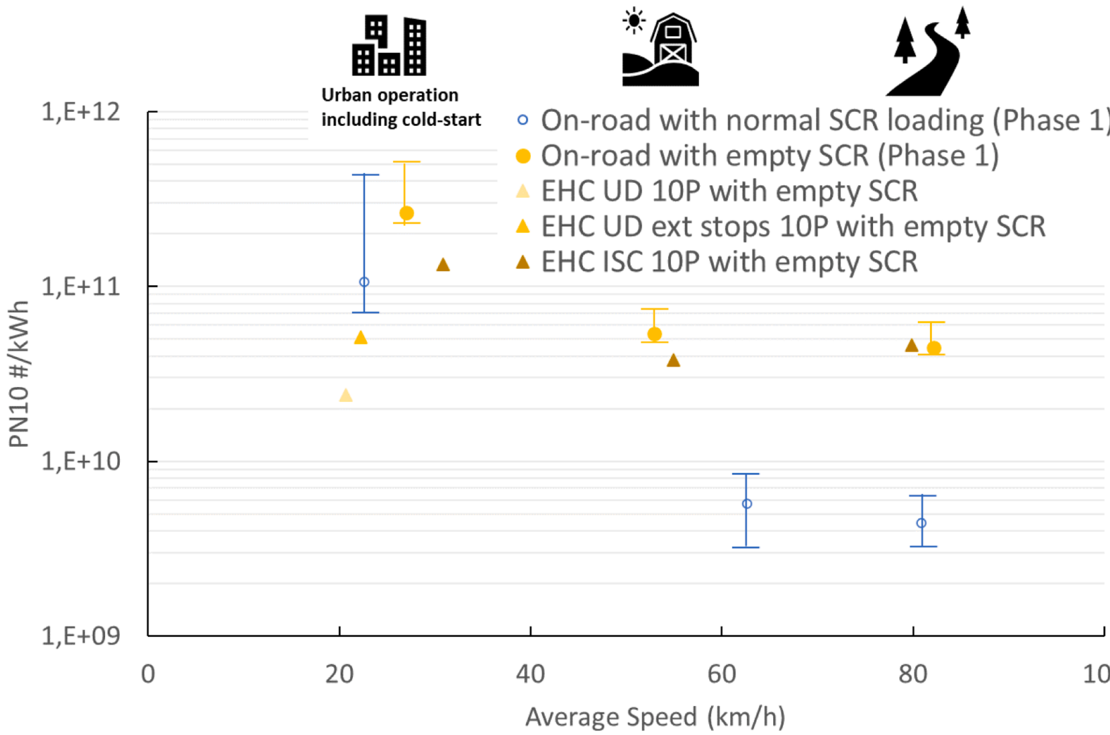

Fig. 13. Summary of PN10 emissions of urban delivery, urban delivery with extended stops and in-service conformity routes.

every test completed. The preconditioning depleted the ammonia from the SCR and incentivized the passive regeneration of the filter. Even within these severe testing conditions the results show ultra-low NOx emissions achieved by the vehicle.

The implementation of the active thermal management in the system did not have a major impact on other measured non-regulated emissions, including NH_3 and N_2O. NH_3 was extremely well controlled by the ammonia slip catalyst, and the N_2O emissions were kept at the similar level to what was seen in tests without the EHC activated. On the PN10 emissions, results show lower production of particulates in every test, although limited data is available to investigate how much can be attributed to the use of EHC.

6. Outlook

Greenhouse gas (GHG) accumulation is to be minimized to stay within the limited available GHG budget to achieve the Paris Climate Agreement. Thus, a holistic approach to reduce these emissions from road transport is required, allowing all available powertrain technologies to contribute to reduce CO_2 emission. In coming years and decades, the technology progress on heavy-duty transport will see hybrid electric applications, as well as full electric and fuel cell vehicles.

Hybrid ICE vehicles will be equipped with emission control technologies which fully operate in combination with drop-in sustainable renewable fuels. This could enable simultaneous ultra-low pollutant emissions and a substantial reduction in CO_2 emissions in an objective Well-to-Wheel assessment.

The AECC heavy-duty diesel demo vehicle will be tested with HVO and e-diesel. Urban delivery and in-service conformity test will be conducted with these sustainable renewable fuels. The objective is to demonstrate the compatibility of such sustainable renewable fuels with modern state-of-the-art technologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgments

The authors would kindly like to thank the members of AECC for supplying the catalyst and filter components and for their highly valuable contributions to this study; as well as the International Platinum Group Metals Association (IPA) and Corning Inc. for their financial support. Thanks to Daimler Trucks for providing the basic production truck and FEV for their continuous support during the development of this project.

References

[1] COM, 789 final - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, in: Sustainable and Smart Mobility Strategy – putting European transport on track for the future 2020, 2020.

[2] COM/2021/550, Final - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, in: 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, 2021.

[3] Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC.

[4] P. Mendoza Villafuerte, et al., Real world emissions of Euro VI Heavy-duty vehicles. SAE Tech. Pap., 2021-01-5074, 2021.

[5] P. Mendoza Villafuerte, et al., Ultra-low NOx emissions with close-coupled emission control system on a heavy-duty truck application, in: 30th Aachen Colloquium Sustainable Mobility 2021, 2021.

[6] P. Mendoza Villafuerte, J. Demuynck, D. Bosteels, T. Wilkes, L. Robb, M. Schönen, Demonstration of extremely low NOx emissions with partly close-coupled emission control on a heavy-duty truck application, in: 42nd International Vienna Motor Symposium 2021, 2021.

[7] T. Selleri, et al., Measuring emissions from a demonstrator heavy-duty diesel vehicle under real-world conditions moving forward to euro VII, Catalysts 12 (2022) 184.

[8] C. Sharp, C.C. Webb, G. Neely, M. Carter, S. Yoon, C. Henry, Achieving ultra low NOX emissions levels with a 2017 heavy-duty on-highway TC diesel engine and an advanced technology emissions system—thermal management strategies, SAE Int. J. Engines 10 (2017) 1697–1712.

[9] J. Ximinis, et al., NOx emissions reduction analysis in a diesel Euro VI Heavy Duty vehicle using a thermoelectric generator and an exhaust heater, Fuel 301 (2021), 121029.
[10] V. Schmeisser, M. Weibel, L. Sebastian Hernando, I. Nova, E. Tronconi, M. P. Ruggeri, Cold start effect phenomena over zeolite SCR catalysts for exhaust gas aftertreatment, SAE Int. J. Commer. Veh. 6 (2013) 190–199.
[11] DIN EN 15940 Automotive fuels - Paraffinic diesel fuel from synthesis or hydrotreatment. Available online: https://www.din.de/en/wdc-beuth:din21:309170058.