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TNO report

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The Netherlands In-Service Emissions Testing Programme for Heavy-Duty Vehicles 2015-2016 – Annual report

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Samenvatting

In opdracht van het Ministerie van Infrastructuur en Milieu voert TNO het steekproefcontroleprogramma voor vrachtwagens en bussen uit. In dit programma meet TNO, op regelmatige basis, de uitlaatgasemissies van deze voertuigen om te onderzoeken hoe schoon ze in de praktijk zijn en of zij aan de Europese normen voldoen. In dit rapport wordt verslag gedaan van het steekproefcontroleprogramma voor vrachtwagens en bussen voor de periode van medio 2015 tot medio 2016.

Inzicht in praktijkemissies van Euro VI vrachtwagens en bussen is belangrijk

Sinds de inwerkingtreding van de Euro VI norm voor de uitlaatgassen van zware voertuigen op 1 januari 2014, richt het meetprogramma zich voornamelijk op het meten en monitoren van de praktijkemissies van dieselvoertuigen, die aan deze norm voldoen. Euro VI voertuigen vertegenwoordigen een snel groeiend aandeel in de Nederlandse vloot.

Effectieve Euro VI normering is belangrijk voor de luchtkwaliteit

Euro VI voertuigen hebben de potentie een bijdrage te leveren aan de verbetering van de luchtkwaliteit. De mate waarin ze dit doen hangt sterk af van de effectiviteit van de Euro VI-eisen voor de praktijkemissies, in het bijzonder voor rijomstandigheden in de stad. Daarom is, naast het vaststellen van de emissiefactoren van deze groep voertuigen een belangrijk doel van het programma het monitoren van de effectiviteit van de Euro VI normering ten aanzien van het halen van lage praktijkemissies.

Euro VI gemiddeld flink schoner

Dankzij de flink aangescherpte Europese Euro VI normstelling, en de technologie die fabrikanten hebben ontwikkeld, stoten nieuwe vrachtauto's en bussen minder schadelijke stoffen uit. Metingen aan vrachtwagens voor langeafstandsvervoer, met geavanceerde Euro VI technologie, lieten zeer lage praktijkemissies van stikstofoxiden (NO_x) zien [TNO 2014a, TNO 2015a]. Ook Euro VI bedrijfswagens in andere toepassingen zijn gemiddeld significant schoner dan eerdere generaties. Euro VI zware voertuigen laten wat dit betreft een ander beeld zien dan Euro 6 dieselpersonenauto's en dieselbestelauto's. Waar bij Euro 6 dieselpersonenauto's en dieselbestelauto's de NO_x-uitstoot in de praktijk niet of nauwelijks is afgenomen ten opzicht van voorgaande euroklassen, is dit bij Euro VI zware voertuigen duidelijk wel het geval [TNO 2016a].

Focus op de effectiviteit Euro VI is nog steeds noodzakelijk

Uit voorgaand onderzoek [TNO 2014a, TNO 2015a] kwam naar voren dat in stedelijke toepassing enkele voertuigen niet zo schoon waren dan je op basis van de normstelling zou mogen verwachten. Een belangrijke aanbeveling van dit voorgaande onderzoek was om voor het vaststellen van emissiefactoren extra voertuigen te testen die in stedelijk gebied worden ingezet. Hiermee kan dan worden getoetst of Euro VI effectief is voor alle representatieve omstandigheden, of dat de praktijkinzet van invloed kan zijn op het emissieniveau van NO_x.

Naast de mogelijke invloed van de praktijkinzet zijn er nog andere zaken die van belang zijn voor de effectiviteit van Euro VI en het halen van lage gemiddelde praktijkemissies voor de voertuigvloot:

- de duurzaamheid van emissiebeheerssystemen,
- storingen,
- manipulatie door de gebruiker en
- het tegen de limietwaarde aan afstemmen van emissies, waardoor een deel van het technisch mogelijke effect van zeer lage praktijkemissies verloren zou kunnen gaat.

Resultaten van het testprogramma met Euro VI voertuigen

Er zijn tot dusver emissietesten uitgevoerd aan 24 Euro VI voertuigen. De testen zijn uitgevoerd met twee systemen:

- PEMS (Portable Emissions Measurement System). Dit is het door de Europese eisen voorgeschreven instrument om de praktijkemissies te testen (in-service conformity).
- SEMS (Smart Emissions Measurement System). Dit is een door TNO ontwikkeld alternatief meetsysteem om de praktijkemissieniveaus van NO_x en ammoniak te screenen. De metingen zijn gedaan onder voor de Nederlandse praktijk representatieve omstandigheden.

Euro VI categorie	Aantal voertuigen getest	Instrumenten	Type testen
Zware vrachtwagen (N3), diesel	2	PEMS	in-service conformity testen en praktijktesten
	6	PEMS + SEMS	in-service conformity testen en praktijktesten
	5	SEMS	praktijk screeningstesten
Lichte vrachtwagen (N2), diesel	5	SEMS	praktijk screeningstesten
Bus (M3), diesel	3	PEMS	in-service conformity testen en 1 herhaling van een praktijktest
	3	SEMS	praktijk screeningstesten

In-service conformity in orde

In de periode vanaf 2014 zijn negen Euro VI voertuigen getest door het uitvoeren van praktijkmetingen over de formele in-service conformity test. Resultaat hiervan is dat deze negen voertuigen voldoen aan de eisen die de Europese wetgeving stelt aan emissies van in gebruik zijnde voertuigen.

Resultaten van de screeningtesten

Naast de formele testen zijn aan een tiental andere voertuigen speciale testen uitgevoerd om het emissieniveau te 'screenen'. Deze screeningstesten, die een goedkoop indicatief alternatief vormen voor de formele in-service conformity test met PEMS, dienen in het meetprogramma als voorselectie voor de in-service conformity testen. De testen hebben voor vier van de tien voertuigen geleid tot de beslissing voor een – nog uit te voeren – vervolgonderzoek om te toetsen of de voertuigen aan in-service conformity eisen voldoen. De resultaten van de screening zijn indicatief en worden slechts gebruikt om te bepalen of binnen het meetprogramma een vervolgonderzoek naar in-service conformity nodig is.

Uitstoot van stikstofoxiden (NO_x) van Euro VI voertuigen bij stedelijk gebruik

De testen bevestigen dat Euro VI voertuigen in stedelijk gebruik in de praktijk nog niet in álle gevallen schoon zijn. Het emissieniveau van NO_x is bij stedelijke inzet en lage snelheden nog sterk afhankelijk van de daadwerkelijke rijomstandigheden. Over het algemeen geldt dat de NO_x emissies toenemen bij afnemende gemiddelde snelheid. Stedelijke inzet laat zich vaak kenmerken door een lage gemiddelde snelheid. Maar er zijn ook verschillen tussen voertuigen onderling. Het ene voertuig is beter in staat om bij stedelijke inzet zeer lage NO_x emissies te halen dan de ander.

Effecten koude start op de emissie van NO_x

Een onderzoek naar de bijdrage van de koude start aan het totaal van de NO_x uitstoot wees uit dat ongeveer 17% van de totale NO_x uitstoot wordt geproduceerd tijdens of direct na de koude start (voor de geteste voertuigen bij milde omgevingstemperaturen). Het wordt aanbevolen om in het vervolgprogramma te testen bij diverse, voornamelijk lagere, representatieve Nederlandse omgevingstemperaturen. Voorts wordt het aanbevolen om de koude start op te nemen in de Europese PEMS praktijktestprocedure.

Uitstoot van ammoniak

Euro VI voertuigen met een SCR emissiebeheerssysteem stoten potentieel ammoniak uit. Testen aan tien voertuigen lieten wisselende ammoniak emissieniveaus zien tussen de voertuigen onderling. De gemiddelde concentratie van ammoniak varieerde per voertuig van gemiddeld 1 tot 18 ppm.

Veroudering van emissiebeheerssystemen

De Europese wetgeving voorziet in eisen voor de emissies over de levensduur van een voertuig. Hiermee wordt in principe een mogelijk effect van veroudering op de emissies gereguleerd. Er is echter maar weinig bekend over de effecten van veroudering op de emissies van moderne emissiebeheerssystemen. Eventuele effecten van veroudering zijn ook van belang voor het vaststellen van de emissiefactoren. Daarom worden in het meetprogramma de emissies van één veel verkocht voertuig jaarlijks gemeten. Tot dusver (380.000 km) zijn van dit voertuig de NO_x emissies laag. Het wordt aanbevolen om, nu er meer voertuigen met een flink aantal kilometers op de teller in de vloot komen, deze voertuigen op te nemen in het testprogramma om de mogelijke effecten van veroudering breder te kunnen monitoren.

De Europese typegoedkeuring is niet altijd gebaseerd op testen over de representatieve rijpatronen

De Europese praktijktest voor (motoren van) zware bedrijfswagens stelt nog geen eis dat elk voertuig moet worden getest in zijn beoogde inzet. Dit betekent dat een voertuig prima kan presteren over een formele praktijktestrit, terwijl de NO_x emissies tijdens de normale inzet nog steeds hoog kunnen zijn vanwege de specifieke inzet van het voertuig. Het gaat voornamelijk om voertuigen voor speciale toepassingen, zoals vuilniswagens, straatveegmachines, maar het kan ook autobussen betreffen. Dit fenomeen kan tot effect hebben dat praktijkemissies van deze specifieke voertuigen hoger zijn dan je op basis van de normstellig zou verwachten.

Hoe dit programma verder bijdraagt aan verlaging van praktijkemissies

De Euro VI regelgeving wordt op het gebied van stedelijke emissies verder verbeterd.

Vanwege de genoemde wisselvallige NO_x emissies in stedelijke toepassing en bij lage rijsnelheden, bleek het wenselijk om de bestaande Europese praktijktesten voor zware bedrijfswagens op dit punt te verbeteren. Nederland heeft de meetdata uit dit programma ter beschikking gesteld aan de werkgroep in Brussel die de praktijktesten evalueert en heeft aan de discussies bijgedragen met als doel de praktijktest te verbeteren. Dit heeft geleid tot een aantal belangrijke concrete wijzigingen die met name stedelijke inzet nadrukkelijker deel uit laten maken van de praktijktest.

Aanbod om voertuigen te laten testen binnen het steekproefprogramma

Het Ministerie van Infrastructuur en Milieu biedt concessieverleners en grote fleetowners, die bijvoorbeeld op het punt staan om Euro VI voertuigen aan te schaffen, de mogelijkheid aan om testen te laten uitvoeren binnen het steekproefprogramma voor zware voertuigen. Deze testen kunnen dan een rol spelen in de aankoopbeslissing zodat voor het in de praktijk schoonste voertuig kan worden gekozen. De testen kunnen tijdens de dagelijkse inzet van het te testen voertuig worden uitgevoerd. De kosten van de testen komen voor rekening van het steekproefprogramma dat TNO uitvoert in opdracht van het ministerie.

Summary

Contracted by the ministry of the environment and infrastructure, TNO runs the in-service testing program for heavy-duty trucks and buses. In this program TNO measures on a regular basis the tail-pipe emissions of these vehicles, to investigate how clean they are in the real-world and if they comply with the formal European requirements. This report describes the tests and results of the program for the period mid-2015 to mid-2016.

Insight in real-world emissions of Euro VI trucks and buses is important

Since Euro VI entered into force, the program mainly aims at testing and monitoring the real-world emissions of diesel vehicles that have been type approved according to that standard. These vehicles represent a rapidly growing share in the Dutch heavy duty vehicle fleet.

Effective Euro VI regulation is important for air-quality

Euro VI vehicles can potentially make a contribution to improving air-quality. How much, depends on the actual effectiveness of the Euro VI requirements, specifically for real-world emissions in urban driving conditions. That is why, next to the determination of emission factors from the test data, an important goal of the programme is to monitor of the effectiveness of the Euro VI regulation, in particular for achieving low real-world emissions.

Euro VI much cleaner on average

Thanks to the Euro VI regulation and the technology that was developed by the manufacturers to anticipate to the stricter requirements, heavy-duty vehicles emit significant less noxious emissions in the real-world. Tests with Euro VI long-haulage trucks, equipped with advanced Euro VI technology, showed very low real-world NO_x emissions over routes which are representative for this category [TNO 2014a TNO 2015a]. Most recent insights show as well that other Euro VI truck and bus categories are cleaner on average than earlier generations.

Euro VI heavy-duty vehicles show another picture than Euro 6 passenger cars and vans. The real-world NO_x emission of Euro 6 passenger cars and vans hardly decreased compared to previous emission stages, while for Euro VI heavy-duty vehicles the decrease is significant.

Focus on the effectiveness of Euro VI is still necessary

Previous research [TNO 2014a, TNO 2015a] already concluded that under urban driving conditions some vehicles are not as clean as one might expect based on the requirements for Euro VI. An important recommendation was to measure additional vehicles which are mainly operated in urban areas. In this way, it can be tested whether or not Euro VI is effective for all representative conditions. Next to the possible effects of real-world use, there are some other issues that are important for the effectiveness of Euro VI and the accomplishment of average low emissions of NO_x of the Dutch heavy-duty vehicle fleet. Those issues are:

- the durability of emission control systems,
- malfunctions,

- manipulation by the user and
- the possibility to tune the emission levels of very well performing vehicles closer to the limits, resulting in the loss of a part of the achievable emission reduction.

Results of the test programme with Euro VI vehicles

So far, emissions tests have been performed with 24 Euro VI heavy-duty vehicles. The tests have been executed using two instruments:

- PEMS (Portable Emissions Measurement System).This is the instrument which is formally prescribed in the European Euro VI regulation for testing real-world emissions.
- SEMS (Smart Emissions Measurement System). This is an alternative measurement system developed by TNO. The SEMS is used to screen the real-world emissions of NO_x and NH_3 in every day operation. The measurements have been executed under representative Dutch conditions.

Euro VI category	Number of vehicles tested	Instruments	Type of tests
Heavy truck (N3), diesel	2	PEMS	in-service conformity tests and real-world tests
	6	PEMS + SEMS	in-service conformity tests and real-world tests
	5	SEMS	real-world screening tests
Light truck (N2), diesel	5	SEMS	real-world screening tests
Bus (M3), diesel	3	PEMS	in-service conformity tests and 1 repetition of a real-world test
	3	SEMS	real-world screening tests

In-service conformity is OK

All nine vehicles with Euro VI engines, which have been checked according to the formal European on-road PEMS test procedures as of 2014, comply with the requirements for vehicles and engines in-service.

Results of screening tests

Next to the formal tests real-world tests with SEMS have been executed to ‘screen’ the NO_x emission performance of ten Euro VI diesel vehicles. The tests, which form a cheap indicative alternative to the formal in-service conformity test with PEMS, serve as a way to make a pre-selection for the formal in-service conformity test. For four vehicles the screening test has led to the decision to perform follow-up tests at a later stage to check the in-service conformity. The results of the screening test are indicative and only used to decide whether or not follow-up tests are to be performed within the measurement programme.

NO_x emissions of vehicles operated in urban applications

The tests confirm that Euro VI vehicles are not always clean in urban driving conditions. For this type of operation at low speeds, the NO_x emissions rather depend on the actual driving circumstances. Generally, the NO_x emissions tend to increase when the average speed decreases. Urban driving is often characterized by low average driving speeds. Also different vehicles show different emissions levels at these driving conditions. One vehicle manages better to accomplish low noxious emissions during urban driving than the other.

Effects of cold starts

An investigation into the contribution of the cold start emissions to the total of the NO_x emissions showed that about 17% of the total emissions of NO_x is produced during or just after the cold start (for the tested vehicles under given mild ambient temperatures). It is therefore recommended to perform more tests with Euro VI vehicles at lower representative ambient temperatures and to include requirements for the cold start emissions in the European PEMS procedure.

Ammonia emissions

The effective NO_x emission abatement technology in heavy-duty Euro VI involves an SCR emission reduction system and the use of ureum (AdBlue), which is converted into ammonia after injection in the tailpipe, to react with NO_x to harmless components. Dependent on circumstances ammonia may be emitted. The emission levels and emission behaviour was investigated for a group of ten vehicles. Ammonia concentrations differ a lot among the heavy-duty vehicles tested in real-world driving. Test average NH_3 concentrations vary from 1 to 18 ppm among vehicles.

Durability of emission control devices

The EU emission legislation foresees in measures to regulate emissions during the useful life of an engine. Even though Euro VI technology is thoroughly tested, no data is publically available about the durability of the new technology. Emission data over the useful life and insight into ageing of Euro VI technology is necessary to take account of possible ageing effects for the emission factors.

A series of three annual tests on one main stream heavy-duty engine have shown no significant increase in NO_x emissions over 380.000 km of real-world operation. Because the first Euro VI vehicles start to accumulate significant amount of kilometres, it is recommended to start to include these vehicles in the test selection to have a broader monitoring of the ageing of emissions.

In the European real-world test some special vehicles are not yet checked under normal conditions of use

Certain vehicles do not have to be tested over their normal operation profiles. This means that a vehicle can perform well over a formal PEMS trip, but may in practise still have high NO_x emissions due to the specific use of the vehicle. This may account for instance for refuse collection vehicles, cleaning vehicles and buses. The result is that the real-world NO_x emissions may be higher than one might expect, based on the formal requirements.

How the program contributes to the further reduction of real-world emissions

The Euro VI regulation will be further improved to reduce urban emissions of NO_x

Because of the sometimes high real-world emission of NO_x in urban driving conditions and at low speeds, it became desirable to improve the European emission regulation at this point. The Netherlands provided the test data and insights from this program to the working group in Brussels that evaluated the real-world test procedures. Furthermore, the Netherlands contributed to the discussions that have been held, with the goal to increase the effectiveness of the Euro VI procedures in order to obtain low real-world emissions of NO_x under urban driving conditions. This has led to a number of important amendments to the PEMS test procedures which will result in a more explicit inclusion of urban driving conditions in the requirements.

Offer to test vehicles within the in-service testing programme

Measurements are offered by the Ministry of the Environment and Infrastructure to those stakeholders who like to base their purchase decisions for new clean vehicles upon information obtained from real-world emission tests. This is especially important because stakeholders are offered more than one option for going greener, and insight in real-world emissions performance can help to make well-founded choices. Test can be performed during everyday operation and the costs for the tests are borne by the programme.

Contents

1 Introduction

1.1 Background

Road transport is of great importance for the economy of the Netherlands, but road transport also contributes significantly to the local emission of pollutants and greenhouse gas emissions. This was recognized decades ago in the beginning of the nineties by the Ministry of the Environment and an incentive programme was started to stimulate the purchase of clean and low-noise heavy-duty vehicles. Since then, TNO runs an emissions surveillance programme for the ministry in which it *measures and monitors* the tail-pipe pollutant emissions of heavy-duty vehicles, *checks the compliance* with national and later on also with European standards, *determines trends* in emissions and *determines the emission factors* which are needed to predict local air quality and estimate national total emissions of transport.

To contribute to the development of effective heavy-duty emission legislation, the knowledge and data that is gathered in the programme is also shared in the working groups in Brussels. Especially for Euro VI, the latest standard that entered into force in 2014, many important changes were implemented and the implementation of more improvements is scheduled. This is done with the ultimate goal to decrease the pollutant emissions at the source, under real-world driving conditions.

First generation Euro VI diesel heavy-duty vehicles much cleaner on average

Previous research [TNO 2014a, TNO 2015a] reported on emissions measurements on Euro VI trucks and buses and concluded that the new and more stringent Euro VI legislation has led to significantly lower real-world emissions of the long haulage vehicles.

One of the major improvements in the legislation was that for Euro VI, for the first time real-world testing of the emissions with PEMS (Portable Emissions Measurement System) became mandatory. Another major improvement of the legislation was the implementation of new tests for the particle emissions. The manufacturers anticipated to the new Euro VI requirements by development and application of state-of-the-art emission reduction technology that on average reduces real-world NO_x and particle emissions of new heavy-duty vehicles drastically.

Focus on effectiveness

With the very low emissions of new Euro VI long haulage trucks it becomes important to monitor whether the low emissions of these vehicles sustain over time and whether other categories of heavy-duty vehicles will follow this trend. Besides the drastic reduction of tail-pipe emissions previous research [TNO 2014a, TNO 2015a] also concluded that some vehicles, operated in urban driving conditions, show a mixed performance regarding NO_x emissions. In general, there still is little information available about these and other driving conditions and other vehicle categories that rapidly entered the Dutch fleet after the Euro VI truck engines for long-haulage vehicles were introduced. Furthermore, the effectiveness of Euro VI also depends on the user, because the exhaust cleaning systems need to be well-maintained and not tampered with over the life time of the vehicle.

These and other issues may potentially reduce the success of Euro VI:

- Urban driving conditions, which are not exclusively regulated by the current real-world PEMS tests.
- Tuning of the emission performance closer to the formal limits.
- Special vehicle categories that are not checked in their real driving conditions.
- Ageing/durability of the emission control devices.
- Failures of the exhaust gas cleaning systems and repair and maintenance.
- Manipulation by the user.

These actions are already taken to control these issues:

- The European Euro VI legislation and the Euro VI testing procedures concerning tail-pipe emissions are further improved, with a focus on urban driving conditions. Objective data from this programme on the emission performance of vehicles are used as a foundation for discussions in Brussels about further improvements of the emissions legislation.
- Dutch fleet owners are helped to choose the cleanest technology, by offering tests that can be performed before a vehicle or fleet of vehicles is purchased and stakeholders are kept informed about emission performance of vehicle technology by disseminating the information that is obtained by the programme.

1.2 Aim and approach

The general aim of the Netherlands in-service testing programme for heavy-duty vehicles is to measure the emissions that are needed for the determination of the emissions factors and to gain insight into trends in real-world emissions of generations of heavy-duty vehicles, under the usage conditions relevant for the Dutch situation.

2015-2016 test programme

Given the conclusions from the earlier studies [TNO 2014a, TNO 2015a] and the need for further insights in Euro VI emission performance, the 2015-2016 test programme will continue to test representative Euro VI vehicles for the determination of emission factors and screen the in-service conformity of the emissions of heavy-duty vehicles. More specifically, the programme will:

- Monitor the real-world emission performance of NO_x, NO_2 and NH_3. In the view of air-quality problems in Dutch city centres with NO_2, in particular urban or low speed driving conditions are considered, hereby focusing on testing the emissions performance of Euro VI diesel vehicles that are typically used in urban applications.
- Monitor the stability and durability of engine and emission reduction systems,
- Contribute to the further improvement of the European real-world test procedures with PEMS to better control urban NO_x emissions.
- Consider methods to check for possible manipulation of the exhaust gas cleaning systems by the user.
- Collect information to establish emission factors for the (inter-)national models which calculate pollutant emissions and CO_2 emissions and which are used for air-quality predictions.
- Screen the emissions performance of heavy-duty vehicles relative to formal requirements as laid down in EU emission legislation [582/2011/EC] and report the results to the national Type Approval Authority,

- Consider the use of a more cost-effective means to obtain real-world emissions data and to screen heavy-duty vehicle emissions, called SEMS (Smart Emissions Measurement System).
- Compare the emissions during type-approval tests with the real-world emissions to monitor the effectiveness of European legislation and to extend the knowledge which is needed for the improvement of methods to effectively regulate real-world emissions in The Netherlands and the EU.
- Gain insight in the CO_2 emissions of heavy-duty vehicles.
- Provide the stakeholders with objective emission data which could serve as bases to make well-informed purchase decisions for new clean vehicles.

For this investigation, to realize the goals, TNO selects a range of test vehicles and tests them in the real-world, using a combination of two instruments:

1. SEMS, the sensor-based smart emission measurement system is able to quickly screen the NO_x and NH_3 emissions of vehicles and is used to:
   a. Collect large quantities of emission data over longer periods of real-world vehicle usage [Vermeulen et al. 2012c, TNO 2016b]. This data is relevant for the determination for the emission factors as it captures the often still variable emission behaviour of the NO_x emission of modern Euro VI vehicles.
   b. Determine the SEMS Factor, based on which a decision is made whether or not an in-depth investigation is required to further check the in-service conformity within this measurement programme,

2. PEMS, a Portable Emissions Measurement System which is the formally prescribed instrument for European type-approval used to check the in-service conformity [582/2011/EC] and as such is a widely accepted method to measure real-world emissions and determine the in-service emission performance. PEMS, in the case the gas-PEMS measures the exhaust gas components NO_x, NO_2, CO_2, CO and HC and can alternatively measure CH_4 when an additional analyser module is placed. The measurements can take place driving the truck on the road in normal traffic. As such, PEMS yields estimates for real-world emissions performance of the investigated vehicle. PEMS does not yet include a validated method to measure PM (particulate matter).

1.3 This report

The test programme is part of a multi-annual programme that runs since the nineties of the previous century. As such, this test programme follows-up the conclusions and recommendations for tests of the previous programme as reported in [TNO 2014a and TNO 2015a]. These reports concluded that further monitoring of the emission performance of Euro VI vehicles is needed.

This report summarizes the results of the test done in the years 2015 and the first half of 2016, which were mostly diesel Euro VI vehicles.

In **Chapter 2** the test programme set-up and the methodology for testing real-world of tail-pipe emissions are summarized. This includes the vehicle selection and a brief description of the emission measurement methods. The complete methodology as used for the programme is reported in [TNO 2016b].

In **Chapter 3** the results of the test programme are presented and discussed.

The results focus 1) on measuring real-world emissions for the determination of emission factors and trends in real-world emissions and 2) on screening the conformity of the vehicles in-service, either with a screening test with SEMS or with a formal PEMS test.

More specifically, the following topics are discussed in chapter 3 of this report:

- Real-world emissions of heavy-duty vehicles:
  - Real-world NO_x emissions of diesel Euro VI heavy-duty vehicles.
  - Ageing of real-world emissions of a diesel Euro VI heavy-duty vehicle.
  - Real-world cold start emissions of NO_x of diesel Euro VI heavy-duty vehicles.
  - Real-world NH_3 emissions of diesel Euro VI heavy-duty vehicles.
- Screening and in-service conformity:
  - NO_x and NH_3 screening tests of Euro VI diesel heavy-duty vehicles with a Smart Emission Measurement System (SEMS).
  - In-service conformity tests of diesel Euro VI heavy-duty vehicles with PEMS.

Chapter 4 discusses the developments of the European real-world test procedures.

Chapter 5 summarizes the conclusions and recommendations.

2 Test programme

2.1 Stepped approach using SEMS and PEMS

The general approach of the programme is to use two methods for emissions testing, called SEMS and PEMS. The instruments SEMS and PEMS are both used according a standard schedule in which the data required for emissions factors, emission performance screening and in-service conformity is obtained, see Figure 1.

Emission factors

The merit of the SEMS is that it can measure NO_x emissions and NH_3 emissions over longer periods of time during every day operation of a vehicle. For the determination of emission factors for both NO_x and NH_3 this way of testing is preferred over shorter testing with PEMS, because the emissions of these compounds can be quite variable over time. Emissions excursions may occur during longer testing which depend on specific driving conditions and history and which might not have occurred in a shorter test of a few hours.

Emissions performance screening

To check the in-service conformity, normally the formal PEMS test (EU 582/2011: Portable Emission Measurement System) would be carried out. This is a time-consuming and expensive activity. To increase the number of vehicles that can be checked in the measurement programme, TNO has developed a smart screening method which utilizes SEMS. This instrument is used together with a data-evaluation method that simulates the formally prescribed method for in-service conformity testing with PEMS and calculates the 'SEMS Factor'. The SEMS Factor is compared to a threshold (1.5 [-]).

If the threshold is exceeded, it is decided that the vehicle needs further screening tests on another vehicle of the same type, but now applying the formal test routes as used for in-service conformity testing. The SEMS factor indicates a certain likelihood that a vehicle might pass or fail a formal PEMS test. During the process the results are disseminated, i.e. send to the respective vehicles importers and manufacturers and finally to the national type-approval authority.

The methodology for the testing programme, the screening method that uses SEMS and the formal in-service conformity tests with PEMS are described in a separate report [TNO 2016b]. The decision-based flow-chart in which the SEMS and PEMS tests and the evaluation criteria are given is depicted below.

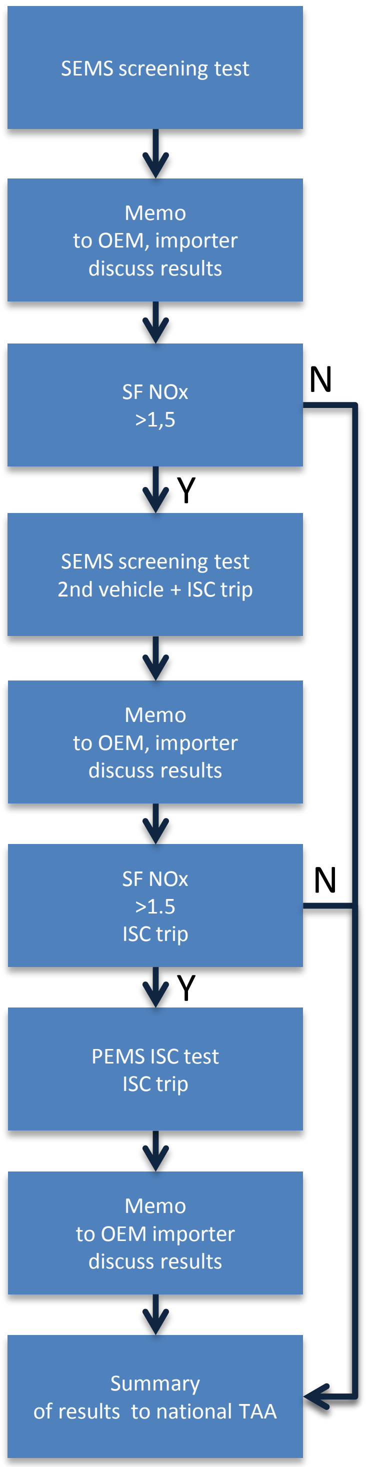

Figure 1 Flow chart with decision moments for conformity testing using SEMS as screening instrument and PEMS as the formal confirmatory testing instrument.

Table 1 Overview of specifications and use of the two measurement systems SEMS and PEMS.

	SEMS	PEMS
	Smart Emissions Measurement System	Portable Emissions Measurements System
Used for	- Real-world emissions in everyday operation - Emissions performance screening	- Real-world emissions - Emissions performance screening - EU in-service Conformity testing
Measured Gases	NO_x, O_2, NH_3, measured with automotive sensors	CO, CO_2, HC, NO, NO_2, NO_x measured with gas analysers
Emissions	Absolute emissions estimated using CAN signals, e.g. fuel rate, manifold air flow CO_2 emission estimated from O_2 (diesel)	Absolute emissions determined with aligned exhaust gas flow measurement
Status	Alternative method/instrument developed by TNO for screening tail-pipe emissions levels and determination of real-world emissions	Formal instrument for on-road testing following the European in-service conformity testing procedure
Emission calculation	CO_2 specific emissions in speed bins (0-50, 50-75, >75) using GPS and ECU data: engine torque and speed, fuel rate, MAF and oxygen as calculated with VESBIN, e.g. NO_x/CO_2 [g/kg] Mean NH_3 concentration over each test and over 30 minute windows	Instantaneous emissions [g/s]: ECE R49 Work specific emissions using ECU engine torque and speed [g/kWh] Distance specific emissions [g/km] CO_2 specific emissions [g/kgCO$_2$]
Data-evaluation	->SEMS Factor (SF) The method simulates the PEMS pass-fail evaluation using SEMS data: - CO_2- or work based Moving Averaging Windows - cold start exclusion - power trheshold (20-15%) - 90-%	-> Conformity Factor (CF) The method applies the formal (582/2011/EC) PEMS pass-fail evaluation rules to the PEMS data using Emroad or PEMS manufacturer scripts.
		

For vehicle selection, tests, follow-up actions and dissemination of the results the following scheme is used:

1 Vehicle selection based on RDW registrations in the Netherlands and performance of a SEMS test (screening) during every days use of the vehicle.
2 Concept memo to the importer. Possibility to discuss results.
3 Test NO_x emissions with the SEMS Factor (SF NO_x >1.5?).
4 If NO_x SF >1.5, perform an additional test with SEMS over the applicable Euro VI compliant in-service conformity test trip with the same or another vehicle with the same engine type.
5 Concept memo to the importer. Possibility to discuss results.
6 Test NO_x emissions with the SEMS Factor (SF NO_x >1.5?).

7 If NO_x SF >1.5, perform a formal PEMS-test over the applicable Euro VI compliant in-service conformity test trip with the same vehicle
8 Concept memo or report to the importer. Possibility to discuss results.
9 Disseminate a summary of all test results to the national type-approval authority, archive the data, inclusion of the data in the annual report with specification of brand and model of the tested vehicles together with an explanation of the method and context, and inclusion of the data in the annual update of the emission factors.

2.2 Vehicle selection

2.2.1 Dutch Euro VI fleet composition

The vehicle selection is focussed on testing representative Euro VI vehicles. Because more than 99% of the fleet of heavy-duty vehicles is running on diesel, the representative selection will only contain this fuel type. It is not excluded that other fuel types or propulsion types are tested on an ad-hoc basis, per special request, but these vehicles are regarded as not representative and are not included in the dataset for the calculation of emission factors.

For the purpose of the determination of emission factors, the fleet is segmented in classes of the maximum mass of the vehicle. The share of N3 vehicles, in the 20 to 50 tonne range is by far the largest. Vehicles of the N3 medium, N2 and M3 class have been selected as well, because of their importance for local urban traffic.

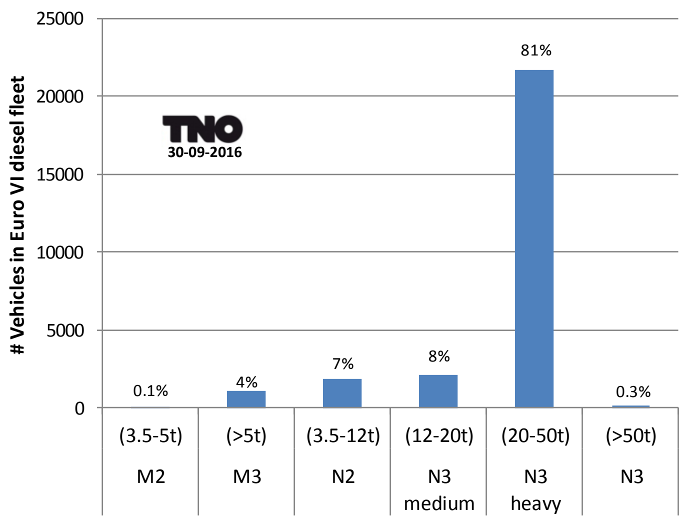

Figure 2 Distribution of diesel Euro VI diesel vehicles over weight classes. Number of registrations in the Netherlands as per January 1 2016 from the RDW database.

Per weight class, ‘make’ and ‘engine type’ are the criteria to rank the number of registered engines in each weight category. The programmes aim is to select to most registered engine types and to test these in the corresponding most representative vehicle types (bus, tractor-trailer, rigid truck, …). In appendix A an overview is given of the vehicle types per weight class, sorted by the number of registrations in the RDW database from January 1, 2016. The tested vehicles are marked, so that the coverage of the Dutch fleet of diesel Euro VI heavy-duty vehicles is shown.

2.2.2 *Vehicles and tests*

Table 2 Overview of heavy-duty vehicles tested in the programme in 2015-2016 and all Euro VI vehicles of the previous programme.

TNO Vehicle Code	License plate	Emission stage	Legislative category, sub category[1]	Fuel	Make	Model	Type	Max. mass [kg]	Tests
SC106	N/A	'VI Proto'	N3 heavy	EN590	Scania	R440 A 6X2/4	Rigid + trailer	50000	PEMS
MB113	BZ-NJ-54	VI	N3 heavy	EN590	Mercedes-Benz	Actros	Tractor semi-trailer	44000	PEMS
SC116	BZ-ZG-48	VI	N3 heavy	EN590	Scania	R440 A 6X2/4	Tractor semi-trailer	50000	PEMS
MB117	BZ-XX-10	VI	N3 heavy	EN590	Mercedes-Benz	Actros	Tractor semi-trailer	44000	SEMS
MA118	M QB 8024	VI	N3 heavy	EN590	MAN	TGM 18.340	Rigid + trailer	50000	PEMS
DA122	99-BBS-2	VI	N3 heavy	EN590	DAF	FT XF	Tractor semi-trailer	46500	PEMS, durability
IV123	79-BBX-7	VI	N3 heavy	EN590	Iveco	AS440T/P Stralis	Tractor semi-trailer	46500	PEMS
VO124	66-BBV-6	VI	N3 heavy	EN590	Volvo	FH460	Tractor semi-trailer	46000	PEMS
SC125	62-BBK-7	VI	N3 heavy	EN590	Scania	P280	Refuse collection	26500	SEMS
MB127	67-BDD-6	VI	N2	EN590	Mercedes-Benz	Atego	Rigid truck	10500	SEMS
MB128	48-BDG-7	VI	M3	EN590	Mercedes-Benz	Citaro	Standard bus	18600	PEMS
MA129	MA N5520	VI	M3	EN590	MAN	Lion's city	Standard bus	18000	PEMS
MB133	48-BDG-7	VI	M3	EN590	Mercedes-Benz	Citaro	Standard bus	18600	PEMS
MA135	51-BFD-7	VI	N2	EN590	MAN	TGL 10.220	Tractor semi-trailer	16740	SEMS screening
MA136	83-BFG-7	VI	N3 heavy	EN590	MAN	TGX	Tractor semi-trailer	27000	SEMS screening
MB137	61-BDS-8	VI	N3 medium	EN590	Mercedes-Benz	Antos	Rigid truck	19000	SEMS screening
DA138	02-BFT-9	VI	N3 medium	EN590	DAF	CF 250 FA	Rigid truck	19000	SEMS screening
MA139	45-BDK-2	VI	N2	EN590	MAN	TGL	Rigid truck	8000	SEMS screening
DA140	72-BFB-3	VI	N2	EN590	DAF	LF 150 FA	Rigid truck	7500	SEMS screening
DA141	64-BDT-1	VI	N3 heavy	EN590	DAF	CF 290 FAG	Refuse collection	27000	SEMS screening
IV142	06-BDT-6	VI	M3	EN590	Iveco	Crossway LE	Standard bus	17800	SEMS screening
VD143	58-BDP-8	VI	M3	EN590	VDL	Citea SLFA-180	Articulated bus	29000	SEMS screening
NN144	BZ-LG-67	Prototype	M3	LNG	MAN	Lion city + EOCV	Standard bus	18600	SORT test
VD145	24-BFH-6	VI	M3	EN590	VDL	Citea LLE-120/255	Standard bus	14870	SEMS screening
VO146	72-BFX-7	VI	N2	EN590	Volvo	FE	Rigid truck	19000	SEMS screening [2]

[1] According 2007/46/EC. Further categorization in 'medium' and 'heavy' for class N3 for the purpose of determination of emission factors. 'Medium' means a maximum mass of 12,000-19,999 kg and 'heavy means a maximum mass of 20,000-50,000 kg.

[2] Invalid test due to SEMS equipment failure, the test will be repeated.

3 Results of the test programme

The first paragraph discusses the results of real-world emissions; the second paragraph discusses the results of emission performance screening and in-service conformity testing.

3.1 Real-world emissions of heavy-duty vehicles

3.1.1 Real-world NO_x emissions of diesel Euro VI heavy-duty vehicles

In this paragraph the real-world NO_x emissions of all tested Euro VI diesel heavy-duty vehicles are presented. The NO_x emissions are expressed in g per kg CO_2 for each vehicle class (N3 heavy, N3 medium, N2 and M3). The emissions are all tested over different test routes and represent emissions from warm engine operation only. This means that the engine coolant temperature was higher than 70 °C. Cold start emissions have been evaluated separately and are presented in paragraph 3.1.3.

Emissions are ‘binned’ in three speed intervals and thus each contains only the data from the specific speed range, including accelerations and decelerations in this speed range. For each vehicle, an indication is given of the typical real-world use or test trip that was driven. **For real-world trips, the real-world emissions of individual vehicles cannot be compared as the routes, driving style and other circumstances probably differ from vehicle to vehicle.** The exercise is done to investigate the variability of NO_x emissions of Euro VI under the normal conditions of use. This variability is important for the determination of emission factors. In case of very low emissions on average, excursions of the emissions may have a large share in the average.

Heavy diesel N3 trucks (>20t)

The tested trucks, mainly tractor semi-trailers and one rigid with trailer, show average NO_x emissions lower than 0.5 g/kg over the reference trip [TNO 2016b] for the three speed bins.

One tractor semi-trailer that was tested during every day use shows NO_x average emissions of 3 g/kg in the speed bin ‘0-50 km/h’. This was probably caused by the real-world driving conditions. For this vehicle the engine idled for relatively long times. Over the test period the share of idling in total driving was 25%.

The two tested refuse collection vehicles in the N3 category show different NO_x emissions. One emits on average about 3 g/kg and one emits on average 0.5 g/kg or less. Both vehicles can’t be directly compared because the emissions depend on these actual driving conditions and the driving conditions were different for the two vehicles.

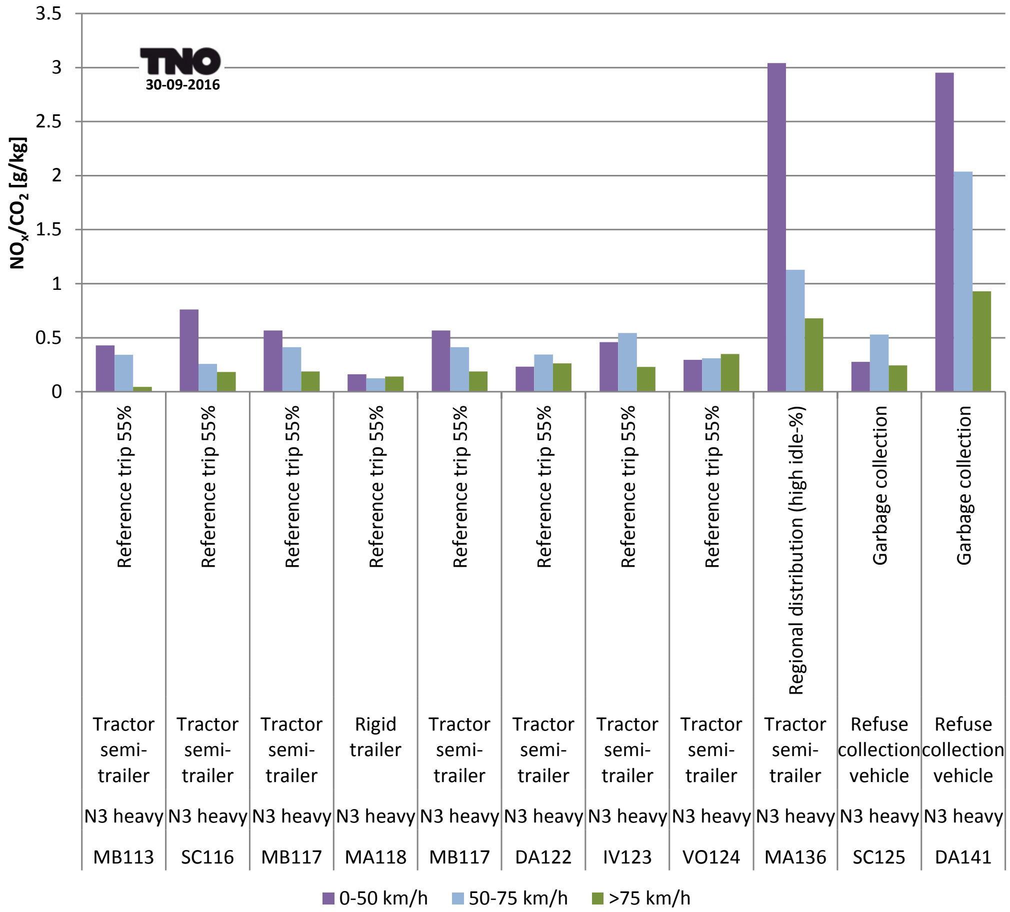

Figure 3 Real-world NO_x emissions of **heavy diesel N3 trucks**, (maximum mass 20000-50000 kg) expressed as NO_x/CO_2. Emissions are binned in speed intervals and represent warm engine operation (coolant temperature is equal to or higher than 70°C). Individual vehicles can't be compared directly because underlying test conditions (test routes, driving styles and ambient conditions) differ and NO_x emissions levels may depend on these circumstances.

N2 trucks and medium heavy diesel N3 trucks (12-20t)

The real-world usage for these vehicles differs from long haulage to local distribution. This also influences the emission level of NO_x. The truck that drives long-haulage routes has low NO_x emissions. Both trucks that run local distribution have higher NO_x emissions, up to 3 g/kg, especially in the lowest speed bins.

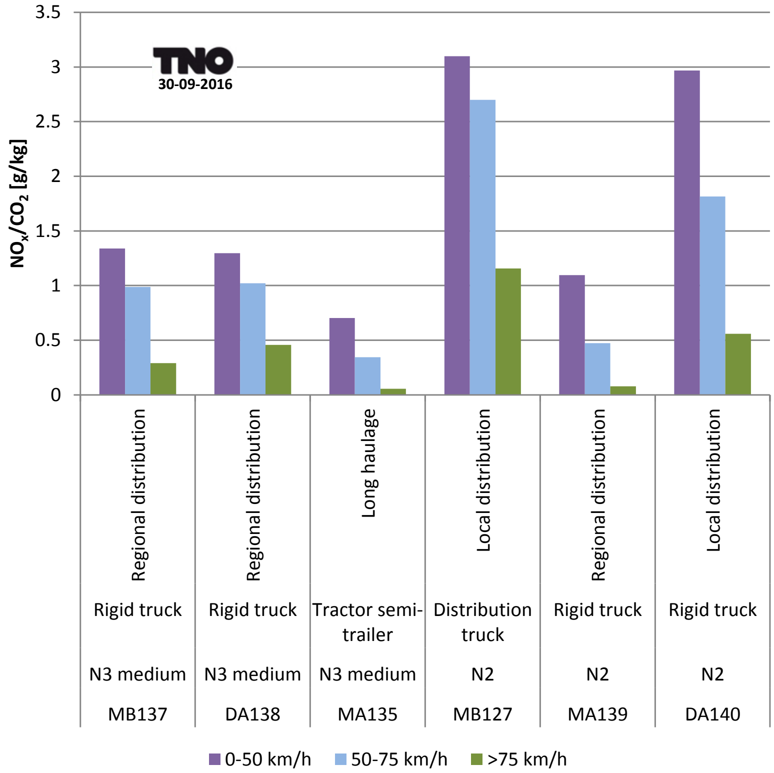

Figure 4 Real-world NO_x emissions of **medium diesel N3** (maximum mass 12000-19999 kg) **and N2 trucks** (3500 – 19999 kg), expressed as NO_x/CO_2. Emissions are binned in speed intervals and represent warm engine operation (coolant temperature is equal to or higher than 70°C). Individual vehicles can't be compared directly because underlying test conditions (test routes, driving styles and ambient conditions) differ and NO_x emissions levels may depend on these circumstances.

M3 buses

One bus shows average NO_x emissions of just above 2 g/kg in the lowest speed bin (0-50 km/h), while the others emit on average around 1.0 g/kg or less.

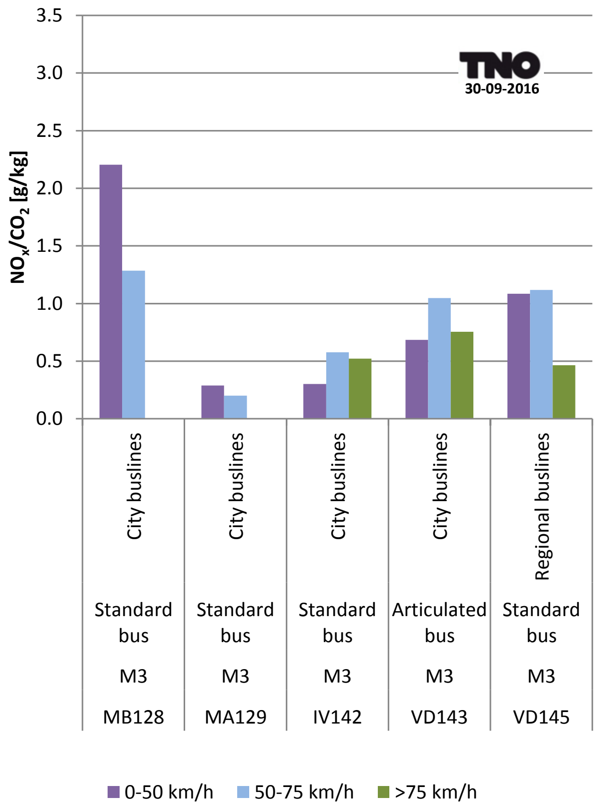

Figure 5 Real-world NO_x emissions of **M3 buses**, expressed as NO_x/CO_2. Emissions are binned in speed intervals and represent warm engine operation (coolant temperature is equal to or higher than 70°C). Individual vehicles can't be compared directly because underlying test conditions (test routes, driving styles and ambient conditions) differ and NO_x emissions levels may depend on these circumstances.

3.1.2 Ageing of real-world emissions of a diesel Euro VI heavy-duty vehicle

Little is known about possible effects of ageing of SCR systems on NO_x emission levels. To monitor the ageing effects for Euro VI vehicles, a test programme is defined in which one vehicle is tested in August each year, until the vehicle has reached it's useful life[1] or until the vehicle is taken out of service.

For the programme a vehicle (DA122) with a representative engine type was chosen. The vehicle is tested so far at three mileages. At the moment of writing this report the vehicle has been tested three times and at the third test repetition the vehicle has run 380.329 kilometres. For all tests the vehicle was in a general good and well maintained condition.

Table 3 Test dates and odometer settings of the vehicle used for assessing aging of real-world emissions

	Year	Test date	Odometer [km]
Fase 1	2014	9-4-2013	29.900
Fase 2	2015	24-8-2015	271.700
Fase 3	2016	1-8-2016	380.329

The NO_x emissions do not show a dependency on mileage. The emission level for NO_x is comfortably low for the tested mileages of the vehicle.

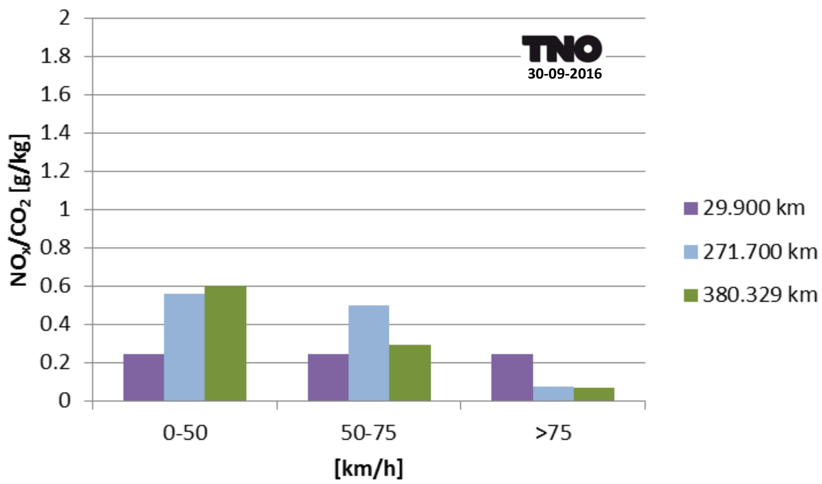

Figure 6 CO_2 specific NO_x emissions over reference trips (55% payload) which are repeated at different mileages (odometer readings) over a part of the use-full life of the vehicle. The NO_x emissions do not show a dependency on mileage. The emission level for NO_x is comfortably low for the tested mileages.

[1] 595/2009. Useful life is 700.000 or seven years for class N3 vehicles >16 ton.

3.1.3 Real-world cold start emissions of NO_x of diesel Euro VI heavy-duty vehicles

3.1.3.1 Introduction

TNO performs real driving emission measurements on heavy-duty vehicles on a regular basis within the Netherlands heavy-duty test programme for the Ministry of Infrastructure and the Environment. In the present work, the data gathered for the vehicles tested in this programme have been analysed to obtain an indication of the real-world share of cold start NO_x emissions, and the variability among vehicles and their use patterns. The data and insights are used for the determination of the emission factors of heavy-duty vehicles.

In the European context, discussions are ongoing how to improve the in-service conformity tests of heavy-duty vehicles in the future. One of the debates is about whether to include cold start emissions of nitrogen oxides (NO_x). The share of cold start emissions could be significant, but previously no independent research had been done on the share of cold starts in real driving NO_x emissions.

For both emission factors and improvements of the real driving tests the goal therefore is to evaluate the significance of real-world cold start NO_x emissions of heavy-duty vehicles.

The following research questions have been formulated:

- When analysing real driving data of heavy-duty vehicles, what is the share of cold starts in the total NO_x emissions? In terms of time share of cold engine conditions, in terms of frequency of cold starts and in terms of duration of cold starts?
- What is the NO_x penalty of cold engine conditions (per unit of time) in terms of average NO_x emissions during cold engine conditions?
- What factors affects the NO_x emissions during cold start and does the cold start emission performance differ among vehicles?

3.1.3.2 Background

By design, selective catalytic reduction (SCR) catalysts function only at temperatures above approximately 170 to 200 °C. Below this effective temperature, NO_x in exhaust gas basically passes through unchanged.
Modern engines use other technologies such as exhaust gas recirculation (EGR) and low-NO_x trap (LNT) to mitigate NO_x emissions, which may be effective at lower temperatures. Therefore it is not trivial that emission levels under cold engine conditions are higher than under hot engine conditions.

Apart from the emission concentrations, the contribution of cold start emissions is also dependent on the frequency of cold starts in real driving, and on the warm-up time. Frequent cold starts and a long engine warm-up time lead to a higher percentage of time driven with a cold engine, potentially leading to a higher share of cold start NO_x emissions.

Over the year 2015 TNO has tested ten heavy-duty vehicles, using a screening measurement device called Smart Emission Measurement System (SEMS). It measures NO_x, NH_3 and O_2 in exhaust gas using automotive analysers. The measurements were done during conventional use of the vehicle by the owner, generally over a 5-day period.

To determine at which point during the measurements the catalyst reaches its effective temperature, the temperature of the exhaust gas after the catalyst can be measured. Because this parameter is not measured by the SEMS, the engine coolant temperature as reported by the vehicle's Controller Area Network (CAN) bus is taken as a proxy. From previous experience it had been established that for heavy-duty vehicles the point in time where the catalyst reaches its effective temperature, more or less coincides with the point that the engine coolant reaches 70 °C.

Both the warm-up time and the cooldown time of the engine are influenced by the atmospheric conditions. The cooldown time is important as well because it can mean the difference between a cold and a warm start if the vehicle has been stationary for a while. All vehicle tests were carried out in the Netherlands over the period May-August 2015, yet naturally the atmospheric conditions such as temperature and humidity varied during the tests and among the vehicles tested.

3.1.3.3 *Approach*

Over 2015 TNO has tested ten vehicles with the SEMS measurement device. During a period of, usually, five days, the NO_x emissions were measured on a second to second basis, and logged. The engine temperature as reported on the CAN bus of the vehicle was logged frequently as well.

Using these data, cold starts were identified with the rule:

Cold engine operation = period of operation where engine coolant temperature ≤ 70 °C

The frequency of cold starts was established by the rule:

Cold start = period of cold engine operation since start of the engine

This means that an engine start is counted as a cold start when the coolant temperature was below 70 °C at the time of the start.

The duration of a cold start is counted from the moment the engine starts until the coolant temperature reaches 70 °C.

3.1.3.4 Results for cold start emissions of NO_x

Table 4 Specification of real-world test conditions for assessing cold start emissions of NO_x.

TNO Vehicle Code	Vehicle type	Lowest night temperature [°C]	Highest daytime temp. [°C]	Average trip length (min)	Time share with cold[1] engine	Cold starts /day	Cold start every... (hr)	Share of cold[1] engine condition in NO_x emissions
DA140	Rigid truck	7.2	25.8	7	7.6%	2.2	1.5	**12.5%**
MA139	Rigid truck	9.7	33.1	8	8.1%	14.8	0.2	**36.8%**
DA138	Rigid truck	7.6	25.0	49	2.6%	0.8	9.7	**6.4%**
MB137	Rigid truck	4.5	22.7	39	3.1%	1.0	5.6	**12.2%**
MA135	Tractor semi-trailer	2.5	25.6	48	3.5%	5.2	3.2	**39.4%**
MA136	Tractor semi-trailer	7.1	31.8	57	4.0%	2.6	2.8	**19.2%**
DA141	Refuse collection vehicle	9.6	25.6	155	3.0%	5.8	2.9	**4.0%**
VD143	Articulated bus	10.3	30.0	80	2.9%	6.5	5.9	**9.8%**
IV142	Standard bus	7.6	23.3	547	3.3%	2.0	10.3	**20.2%**
VD145	Standard bus	12.9	22.1	76	2.9%	1.5	5.0	**13.8%**

[1]Engine coolant temperature below or equal to 70 °C.

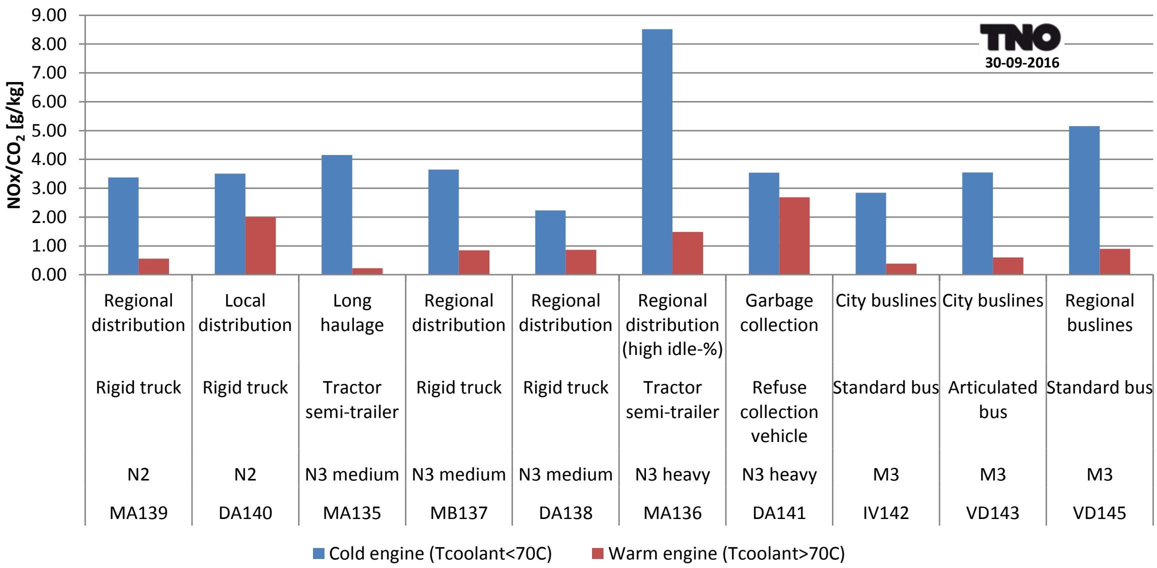

Figure 7 NO_x emission levels during cold and hot engine operation ('cold engine' in the case is defines as an engine with a coolant temperature lower than or equal to 70 °C).

3.1.3.5 Observations and recommendations

- The time share of a cold engine situation is highly variable among the tested vehicles
- The share in the NO_x emissions of the of the cold engine situation is highly variable among tested vehicles
- The number of cold starts per day is highly variable among the tested vehicles
- No relation could be found among these three observations
- Averaged over the ten evaluated vehicles, cold starts contribute 17% to the total NO_x emissions

Factors of importance are:

- The usage pattern of the vehicle (mission profiles, payload and driving style).
- The performance of NO_x emission reduction under hot engine conditions: a better performance increases the share of cold starts.
- The level of the NO_x emissions under cold engine conditions.
- Ambient conditions; measurements are primarily done in mild summer conditions. Tests in colder conditions are recommended to complement the data set.
- Speed of heating up of the engine and aftertreatment system, which depends on heat management of the systems but also on the actual usage pattern (mission profile, payload, driving style).

3.1.4 Real-world NH_3 emissions of diesel Euro VI heavy-duty vehicles

3.1.4.1 Introduction

The effective abatement of NO_x emissions in heavy-duty Euro VI vehicles using SCR involves the use of an aqueous urea solution (AdBlue), of which the urea is converted into ammonia after injection in the tailpipe. In the SCR catalyst the ammonia reacts with the nitrogen oxides, forming harmless components. Dependent on circumstances ammonia slip through the SCR catalyst and escape to the environment. This section gives insight in the total ammonia emissions by heavy-duty vehicles. TNO has performed real driving emission measurements on various heavy-duty vehicles in their daily use, over a period of about a week. These data have been analysed to obtain an indication of:

- the exhaust gas concentration of ammonia (NH_3);
- the absolute level of emissions of ammonia (NH_3) per kg CO_2;
- if NH_3 emissions can be related to driving circumstances like cold start, speed, exhaust gas temperature, accelerations.

3.1.4.2 Approach

Real driving emissions have been sampled during every days operation of a range of SCR equipped Euro VI heavy-duty vehicles, using SEMS (Smart Emission Monitoring System) which included a Delphi ammonia sensor.

3.1.4.3 *Results for NH_3 emissions*

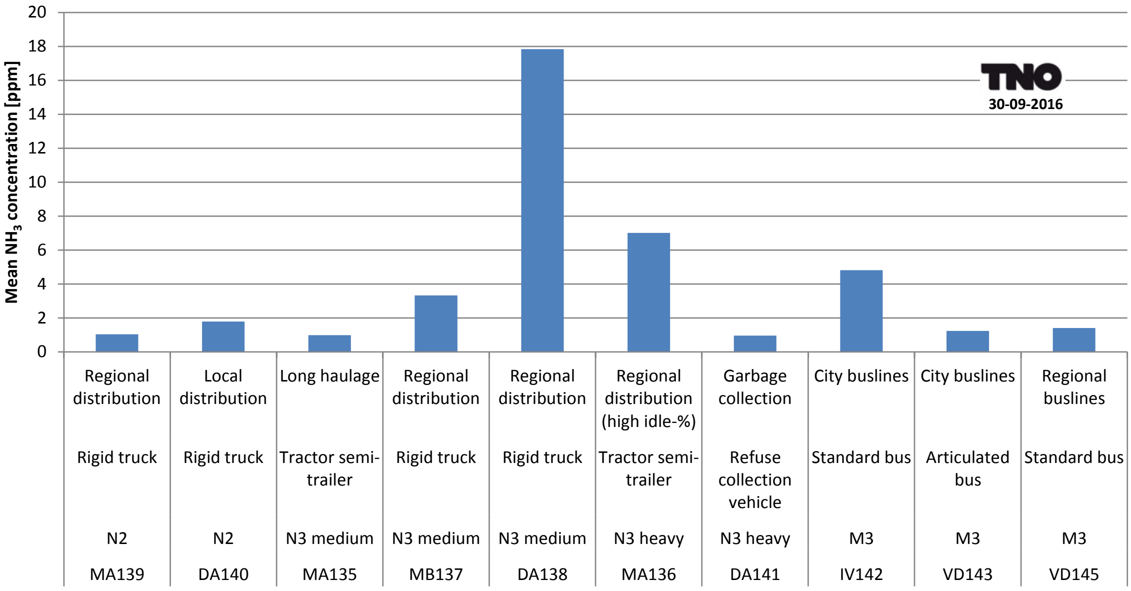

Figure 8 Average tail-pipe NH_3 concentration per vehicle.

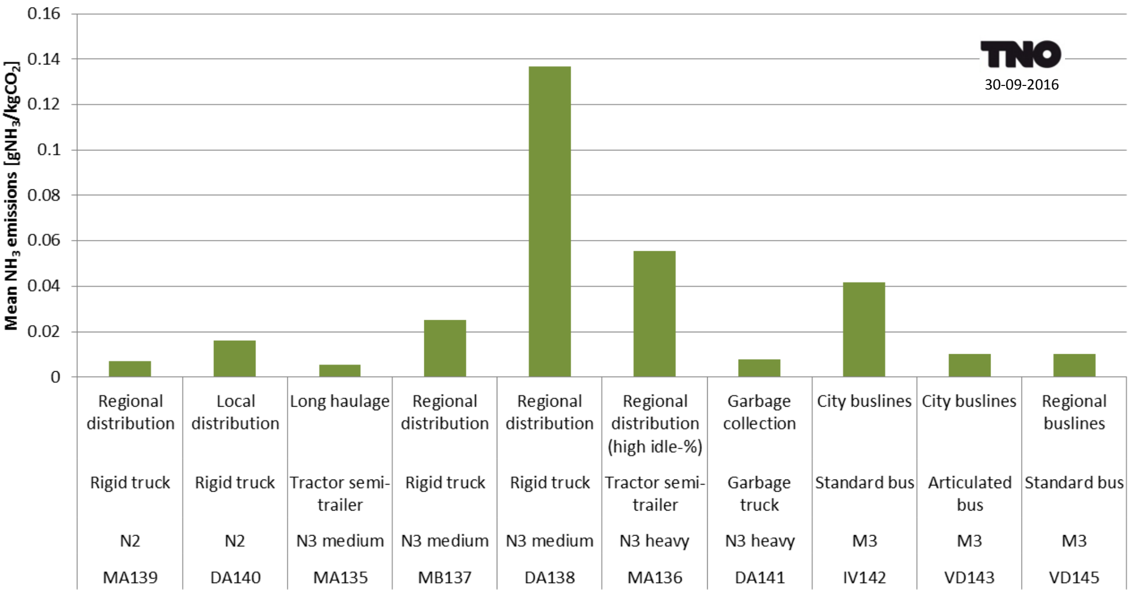

Figure 9 CO_2 specific NH_3 emissions per vehicle.

3.1.4.4 *Observations*

Several vehicles show sudden peaks in ammonia concentration during operation. From the data these peaks couldn't be attributed to certain driving conditions. Given the nature of NO_x emission aftertreatment with Selective Catalytic Reduction (SRC) and the use of urea as reagent and the multitude of factors that can influence instantaneous emissions, no conclusions can be drawn concerning the cause of peaks in these emissions. In general, the multitude of factors that influence instantaneous ammonia emissions are related to the typical behaviour of the an SCR system, which can be summarized as follows:

- NH_3 release is dependent on a number of steps in the urea decomposition process, which occurs with a time delay and at elevated temperature.
- The catalyst functions as a deposition medium for NH_3, and hence buffers NH_3 produced.
- The catalyst has a large heat capacity and is a three-dimensional device.
- The release of NH_3 that does not react with NO_x is therefore probably strongly defined by the 'history'.

General conclusions on the concentration of NH_3 in the exhaust gases of Euro VI heavy-duty vehicles are:

- Ammonia concentrations differ a lot among the heavy-duty vehicles tested in real-world driving.
- Test average NH_3 concentrations vary from 1 to 18 ppm among the vehicles.
- For seven vehicles, the NH_3 concentration average is lower than 10 ppm for all 30-min windows.
- For three vehicles, the NH_3 concentration average exceeds 10 ppm for some 30-min windows.
- One of the tested vehicles has an average exhaust gas NH_3 concentration of 18 ppm which is higher than the 10 ppm that is allowed over the WHTC engine test cycle (10 ppm is the limit value for a standard WHTC cycle).

General conclusions on the emission of NH_3:

- Test average NH_3 emission levels vary from 10-140 mg/kg CO_2 among the vehicles.
- No universal relation could be identified between driving speed and NH_3 emissions.
- No universal relation could be identified between engine coolant temperature and NH_3 emissions.
- In contrast with NO_x emissions, the bulk of the emission of NH_3 occurs in less than 1% of the time.

3.2 In-service conformity and screening programme

3.2.1 In-service conformity tests of diesel Euro VI heavy-duty vehicles with PEMS

The table below presents the results of in-service conformity tests with PEMS. For all vehicles the conformity factors were calculated using the formal pass-fail evaluation method with moving averaging windows. The limit for the conformity factor is a maximum of 1.5 for the regulated gases CO, HC and NO_x for diesel engines. Particle emissions haven't been tested in the in-service conformity tests. For the tested vehicles there are no requirements yet for particle emissions for the in-service conformity tests with PEMS. A measurements procedure to test the particle mass and number is being developed at time of writing this report.

All vehicles that were measured according to the in-service conformity procedure with PEMS have a conformity factor lower than 1.5 for the gasses CO, HC and NO_x.

Table 5 Results of the PEMS in-service conformity tests of Euro VI diesel heavy-duty vehicles.

Vehicle code	Make/model	Euro class	Vehicle cat.	Fuel	PEMS trip	CF NO_x	CF HC	CF CO	CF limit all gases
SC106	Scania prototype	(Euro VI)	N3	Diesel	Euro VI N3	**0.93**	**0.01**	**0.10**	**1.5**
MB113	Mercedes-Benz Actros	Euro VI	N3	Diesel	Euro VI N3	**0.12**	**0.01**	**0.24**	**1.5**
SC116	Scania R440	Euro VI	N3	Diesel	Euro VI N3	**0.85**	**0.14**	**0.20**	**1.5**
MA118	MAN TGM	Euro VI	N3	Diesel	Euro VI N2[1]	**0.46**	**0.14**	**0.13**	**1.5**
DA122	DAF XF FT	Euro VI	N3	Diesel	Euro VI N2[1]	**0.23**	**0.00**	**0.39**	**1.5**
IV123	Iveco Stralis	Euro VI	N3	Diesel	Euro VI N2[1]	**0.20**	**0.09**	**0.35**	**1.5**
VO124	Volvo FH460	Euro VI	N3	Diesel	Euro VI N2[1]	**1.00**	**n/a**	**0.31**	**1.5**
MB128	Mercedes Citaro	Euro VI	M3	Diesel	Euro VI M3	**1.01**	**0.64**	**0.14**	**1.5**
MA129	MAN Lions City	Euro VI	M3	Diesel	Euro VI M3	**0.74**	**0.12**	**0.37**	**1.5**

[1]In some cases N2 PEMS trips were driven instead of the formally required N3 trips. The N2 trip contains a longer fraction of urban driving (40-50%) than the N3 trip (15-25%) and is therefore seen as somewhat more severe with regard to NO_x emissions.

3.2.2 NO_x screening tests of Euro VI diesel heavy-duty vehicles with a Smart Emission Measurement System (SEMS)

Real-world tests with SEMS have been executed to screen the NO_x emission performance of ten Euro VI diesel vehicles in mixed applications, like long-haulage, local and regional distribution and garbage collection. The PEMS pass-fail method was simulated to indicate the emissions performance and to decide whether or not follow-up tests are needed within the testing programme. A criterion is used to decide whether or not follow-up test need to be done. The criterion is called the 'SEMS Factor' (SF) and a threshold of 1.5 is used. The method is explained in [TNO 2016b]. The table below presents the results of these screening tests.

Six out of ten vehicles fulfilled the criterion (SEMS Factor <1.5) and data will be passed on to the National Type-Approval Authority. For four out of ten vehicles, the criterion of 1.5 was not obtained. This can still be caused by the test conditions and the fact that the test does not use the same rules as the formal PEMS test. Thus it can very well be that these vehicles do fulfil the formal PEMS in-service conformity requirements. Therefore, follow-up tests will be performed with these vehicles over the formal test trip. The results of individual vehicles can't be compared as the real-world use was different.

Table 6 Results of the first round of SEMS screening tests. For six out of ten vehicles no follow-up testing is required. Four vehicles will be further investigated by testing them over a formal PEMS trip with SEMS. The evaluation method is explained in [TNO 2016b].

Vehicle code	Make/model	Euro class	Vehicle cat.	Fuel	Real-world use	SEMS Screening Factor NO_x	SEMS SF Limit	Status. Further testing required?
MA135	MAN TGL 10.220	Euro VI	N2	Diesel	Long haulage	**<1.5**	1.5	**N**
MA136	MAN TGX	Euro VI	N3	Diesel	Regional distribution (idle-%>>)	**<1.5**	1.5	**N**
MB137	Mercedes-Benz Antos	Euro VI	N2	Diesel	Regional distribution	**<1.5**	1.5	**N**
DA138	DAF CF 250 FA	Euro VI	N3	Diesel	Regional distribution	**>1.5**	1.5	**Y**
MA139	MAN TGL	Euro VI	N2	Diesel	Regional distribution	**<1.5**	1.5	**N**
DA140	DAF LF 150 FA	Euro VI	N2	Diesel	Local distribution	**>1.5**	1.5	**Y**
DA141	DAF CF 290 FAG	Euro VI	N3	Diesel	Garbage collection	**>1.5**	1.5	**Y**
IV142	Iveco Crossway	Euro VI	M3	Diesel	City buslines	**<1.5**	1.5	**N**
VD143	VDL SLFA	Euro VI	M3	Diesel	City buslines	**<1.5**	1.5	**N**
VD145	VDL LLE	Euro VI	M3	Diesel	Regional buslines	**>1.5**	1.5	**Y**

4 Developments in EU legislation: more improvements still to come

Article 14(3) mandated to EC to introduce ‘off-cycle in-use testing’ after the assessment of the PEMS procedures for heavy duty vehicles. Therefore, the PEMS procedures were assessed and discussed in the PEMS working group to determine whether the PEMS procedures were suitable to perform this ‘off-cycle in-use testing’. The assessment took place, using data from the Swedish and Netherlands in-service emissions testing programmes for heavy-duty vehicles. DG-JRC reported the findings [JRC, 2015], of which the most important findings are:

- A robust assessment of urban emissions is required.
- An investigation is needed for the possible inclusion of the cold start.

The findings from the JRC reports provided the base for the discussions on the further improvement of the PEMS procedures for both gaseous emissions and particulate emissions in the HD-PEMS working group. The discussions have led to proposals for important improvements for the PEMS procedures which are very relevant for the real-world emission performance. These improvements are:

- A stricter control of emissions under urban driving conditions by lowering of the power threshold (from 20 to 10%). (Entering into force January 1st 2019 for all types). Due to this lower threshold, more data from low load, low speed operation is included in the in-service conformity pass-fail evaluation.
- A broadening of the allowed payload range that is to be applied during the PEMS in-service conformity test, from 50-60% to 10-100%. It was requested by the Netherlands to include a wider range because low and high payloads are seen as ‘normal operation’ of the vehicle. Therefor it is highly desirable that a vehicle is compliant under these conditions. The wider allowed payload range not only applies to the compliance testing by the manufacturer as part of the type approval procedure, but also to the compliance testing that member states are allowed to perform to check the in-service conformity of vehicles in-use. The wider payload range will directly enter into force with the first coming amendment, probably end of 2016.
- Improved requirements for the test trips, which include longer urban driving, boundaries for average speeds in sub-parts of the trips and boundaries for test start conditions. These improved requirements will directly enter into force with the first coming amendment, probably end of 2016.

The ‘cold start’ and particle number measurement for PEMS are still under investigation and proposals for test procedures are expected in the next years.

5 Conclusions and recommendations

Emissions tests have been performed with 25 Euro VI vehicles of different categories and under different types of (real-world) usage. Based on these measurements the following can be concluded:

Euro VI diesel NO_x emission performance is mixed in urban driving conditions

To follow-up the recommendations of the previous programme [TNO 2014a, TNO 2015a], next to long-haulage trucks, TNO also tested a sample of distribution trucks, buses and refuse collection vehicles. These measurements show that these vehicles are also cleaner than previous generations. However, these vehicles show strongly varying NO_x emissions, especially under urban driving conditions. Long-haulage vehicles may have increased NO_x emissions too, once they have low speeds on average, as occurs in urban areas and heavy traffic. For most vehicles the NO_x emissions levels are highly related to driving conditions. However some vehicles are able to better sustain the low speeds and still achieve lower NO_x emissions under all conditions than others.

This means that emissions under low speed conditions, like in urban driving and heavy-traffic, are not yet well-controlled by the current Euro VI emission regulation. However, important improvements of the real-world ‘in-service conformity’ test procedure with PEMS in the European legislation are foreseen, that will probably lead to lower NO_x emissions at low speeds in the real-world. Another issue is that certain vehicles, like refuse collection vehicles, do not have to be tested over their normal operation profiles, which means that a vehicle can perform well over a formal PEMS trip, but may in practise still have high NO_x emissions due to the specific use of the vehicle.

In-service conformity and emission performance screening

Real-world tests with PEMS have been executed to check the in-service conformity. Nine relatively new main-stream Euro VI heavy-duty diesel engines were tested in long-haulage configurations. All nine engines have conformity factors for NO_x, CO (carbon monoxide) and HC (hydrocarbon) emissions well below the limit of 1.5.

Real-world tests with SEMS have been executed to screen the NO_x emission performance of ten Euro VI diesel vehicles in mixed applications, like long-haulage local and regional distribution and garbage collection. The PEMS pass-fail method was simulated to indicate the emissions performance and to decide whether or not follow-up tests are needed.

Six out of ten fulfilled the criterion (SEMS Factor <1.5) and data will be passed on to the National Type-Approval Authority. For four out of ten vehicles, the criterion of 1.5 was not obtained. This can still be caused by the test conditions and the fact that the test does not use exactly the same rules as the formal PEMS test. Therefore, follow-up tests will be performed with these vehicles over the formal test trip.

Durability

The new technology to reduce emissions for Euro VI vehicles proved to work well under most circumstances, when the vehicles are new. The emission legislation also foresees in measures to regulate emissions during the useful life of an engine. But even though Euro VI technology is thoroughly tested, no data is publically available about the durability of the new technology, because most Euro VI vehicles are still relatively new and testing over hundreds of thousands of kilometres would take many years. Emission data over the useful life and insight into ageing of Euro VI technology is necessary to take account of possible ageing effects for the emission factors.

A series of three annual tests on one main stream heavy-duty engine have shown no significant increase in NO_x emissions over 380.000 km of real-world operation. Because the first Euro VI vehicles start to accumulate significant amount of kilometres, it is recommended to start to include these vehicles in the test selection to have a broader monitoring of the ageing of emissions.

Cold start emissions

The number of cold starts and the cold start emission levels proved to be highly variable for real-world operation of heavy-duty vehicles and cold start emissions of Euro VI diesel vehicles proved to be substantial and significant on average in the total NO_x emissions. It is therefore recommended to perform more tests with Euro VI vehicles at lower ambient temperatures and to consider the inclusion of requirements for the cold start emissions in the European PEMS procedure.

Ammonia emissions

The effective abatement of NO_x emissions in heavy-duty Euro VI vehicles using SCR involves the use of ureum (AdBlue), which is converted into ammonia after injection in the tailpipe. In the SCR catalyst the ammonia reacts with the nitrogen oxides, forming harmless components. Dependent on circumstances ammonia slip through the SCR catalyst and escape to the environment. The emission levels and emission behaviour was investigated for a group of vehicles. Ammonia concentrations differ a lot among the heavy-duty vehicles tested in real-world driving. Test average NH_3 concentrations vary from 1 to 18 ppm among vehicles. For seven vehicles, the NH_3 concentration average is lower than 10 ppm for 30-minute windows. For three vehicles, the NH_3 concentration exceeds 10 ppm for some 30-minute windows. One of the tested vehicles has an average exhaust gas NH_3 concentration of 18 ppm which is higher than the 10 ppm that is allowed over the WHTC engine test cycle (10 ppm is the limit value for a standard WHTC cycle). It is recommended to continue monitoring NH_3 emissions.

Real-world emission screening for fleet-owners

In a letter[2] to the Dutch parliament, it is written that measurements are offered by the Ministry of the Environment and Infrastructure to those stakeholders who like to base their purchase decisions for new clean vehicles upon information obtained from real-world emission tests. This is especially important because stakeholders are offered more than one option for going greener, and insight in real-world emissions performance can help to make well-founded choices. This is especially important because stakeholders are offered more than one option for going

[2] Kamerbrief 26 november 2015 betreffende actieplan luchtkwaliteit

greener, and insight in real-world emissions performance can help to make well-founded choices. The tests are to be performed within the framework of the Netherlands in-service emissions testing programme for heavy-duty vehicles. The test can be performed during everyday operation and the costs for the tests are borne by the programme.

Evaluation of the European real-world test procedures with PEMS

The Euro VI legislation mandated the European Commission to evaluate the real-world emission test procedure after implementation. The data and insights from the Netherlands test programme on Euro VI trucks and buses were brought in the working group that evaluated the real-world test procedure. Furthermore, the Netherlands contributed to the discussions that have been held, with the goal to increase the effectiveness of the Euro VI procedures in order to obtain low real-world emissions of NO_x under urban driving conditions.

The working group proposed important improvements for the real-world PEMS test which will decrease the NO_x emissions under specific low speed driving conditions:

- A stricter control of emissions under urban driving conditions by lowering the power threshold. More low speed and low load operation will be part of the regulated conditions.
- A much wider range of payload is now considered as normal use of a vehicle and therefore will be part of the regulated conditions.
- Improved requirements for the test trips, which includes longer urban driving.

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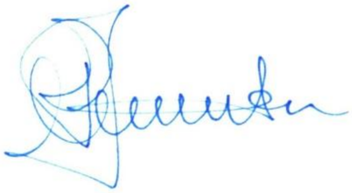
TNO



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A Dutch fleet and vehicles tested (Euro VI diesel)

Euro VI M2

Brand	Engine capacity (cc)	Numbers in fleet	Fraction in M2 fleet	Tested
MERCEDES-BENZ	2143	11	44%	
FORD	2198	5	20%	
VOLKSWAGEN	1968	3	12%	
MERCEDES-BENZ	2987	3	12%	
EVM LIMITED	2143	2	8%	
VDL	2987	1	4%	
Total M2		25	100%	

Euro VI M3

Make	Engine capacity (cc)	Numbers in fleet	Fraction in M3 fleet	Tested
MERCEDES-BENZ	10677	214	20%	
FPT (VDL, IVECO)	8710	181	17%	√
MERCEDES-BENZ	7698	111	11%	√√
CUMMINS (VDL)	6700	107	10%	√
VOLVO	7698	99	9%	
DAF (VDL)	10837	64	6%	
IVECO	6728	39	4%	√
MAN	12419	34	3%	
MERCEDES-BENZ (SETRA)	12809	25	2%	
MAN	10518	24	2%	
Other		156	15%	
Total M3		1054	100%	

Euro VI N2

Make	Engine capacity (cc)	Numbers in fleet	Fraction in N2 fleet	Tested
MERCEDES-BENZ	5132	314	17%	√
MAN	4580	260	14%	√√
DAF	4500	251	14%	√
MERCEDES-BENZ	2143	169	9%	
VOLVO	5132	141	8%	
MERCEDES-BENZ	2987	86	5%	
MAN	6871	75	4%	
IVECO	4485	73	4%	
DAF	6700	71	4%	
MERCEDES-BENZ	7698	62	3%	
Other		354	19%	
Total N2		1856	100%	

Euro N3 VI medium

Make	Engine capacity (cc)	Numbers in fleet	Fraction in N3 medium fleet	Tested
MERCEDES-BENZ	7698	366	17%	√
MAN	6871	265	13%	√
DAF	6700	230	11%	√
VOLVO	7698	213	10%	test failed
SCANIA	9291	180	9%	√
DAF	10837	173	8%	
MERCEDES-BENZ	10677	106	5%	
IVECO	6728	82	4%	
VOLVO	10837	76	4%	
VOLVO	12777	55	3%	
Other		355	17%	
Total N3 medium		2101	100%	

Euro VI N3 heavy

Make	Engine capacity (cc)	Numbers in fleet	Fraction in N3 heavy fleet	Tested
VOLVO	12777	3764	17%	√
SCANIA	12742	3100	14%	√
DAF	10837	3017	14%	√
DAF	12902	2810	13%	√
MERCEDES-BENZ	12809	2536	12%	√√
MAN	12419	1854	9%	√
VOLVO	10837	1155	5%	
MERCEDES-BENZ	10677	796	4%	
MAN	10518	701	3%	
SCANIA	16353	521	2%	
Other		1481	7%	
Total N3 heavy		21735	100%	

Euro VI N3 >50t

Make	Engine capacity (cc)	Numbers in fleet	Fraction in N3 >50t-vloot	Tested
MAN	12419	16	18%	
DAF	12902	15	17%	
VOLVO	12777	13	15%	
DAF	10837	13	15%	
SPIERINGS	12902	8	9%	
SCANIA	12742	5	6%	
SCANIA	16353	5	6%	
MERCEDES-BENZ	12809	4	4%	
MAN	10518	3	3%	
MERCEDES-BENZ	10677	2	2%	
Other		5	6%	
Total N3 >50t		89	100%	