Nederlandse Organisatie voor
toegepast-natuurwetenschappelijk
onderzoek / Netherlands Organisation
for Applied Scientific Research

TNO Science and Industry

Stieltjesweg 1
P.O. Box 155
2600 AD Delft
The Netherlands

www.tno.nl

T +31 15 269 20 00
F +31 15 269 21 11
info-IenT@tno.nl

TNO report

MON-RPT-2010-00969

In-Service Testing Programme for Heavy-Duty Vehicle and Engine emissions; 2006-2009

Date	2 April 2010
Author(s)	ing. R.J. Vermeulen ir. A.R.A. Eijk
Assignor	Ministerie van VROM Directorat-Generaal Milieubeheer, DGM Afdeling IPC 650 t.a.v. de heer ing. H.L. Baarbé Postbus 30945 2500 GX DEN HAAG
Project number	009.01687
Number of pages	91 (incl. appendices)
Number of appendices	4

Executive summary

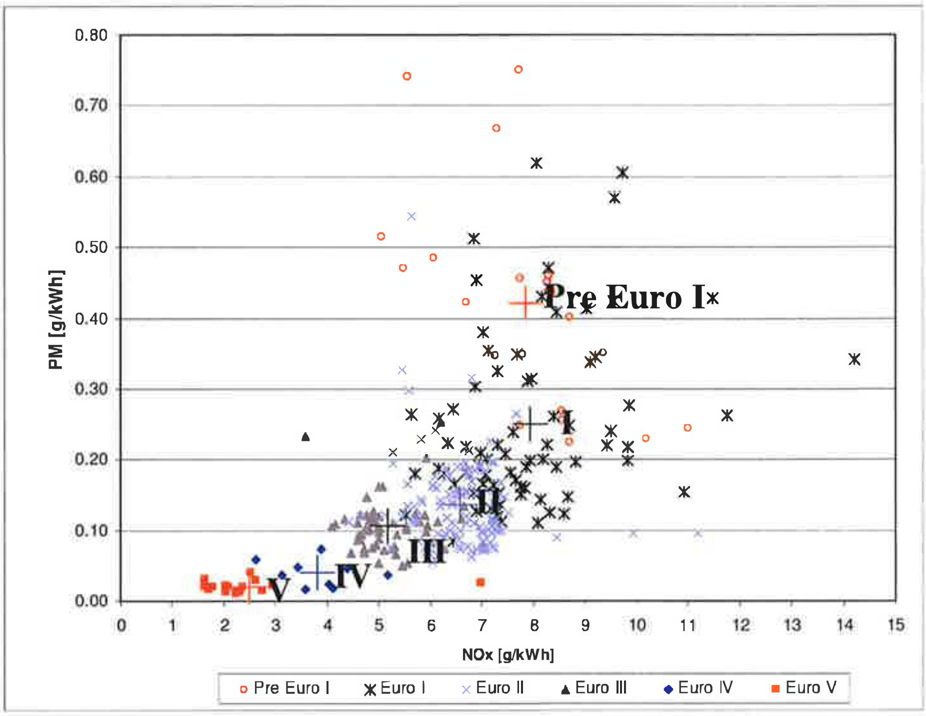
This executive summary presents the most important results and conclusions of the testing programme for the tail pipe emissions of modern heavy duty vehicles and engines. The programme was executed during the period from 2006 to 2009 and was aimed at vehicles with Euro IV (2006-2009) and Euro V certified engines (2009-2013). The Euro V engines however, mainly comprised early versions brought to the market as of 2005, stimulated by foreign, national and local incentives. The programme comprised one part in which engines were tested in their vehicles over a legislative type approval test in the emission laboratory and another part where vehicles were tested in the real world on the road.

Vehicle test results over the legislative European steady state test cycle (ESC) in the emission test laboratory:

- The particulate matter (PM) emissions of Euro IV engines with exhaust gas recirculation (EGR) are very scattered and on average well above the applicable limit. For nitrogen oxides (NOx) Euro IV engines perform somewhat better; on average the limit is only just exceeded.
- For Euro V engines the PM as well as the NOx emissions are on average just above the applicable limit. Regarding the capabilities of selective catalytic reduction (SCR) to reduce NOx Euro V engines are probably very critically tuned.
- For THC (hydro carbons) and CO (carbon monoxide) the Euro IV and Euro V engines performed very well when compared to the limit.

In general, going from pre Euro I to Euro V the emissions of newer engine types, measured over the ESC test, are closer to the applicable emission limits. Furthermore, the emission results of the newer engine types are less scattered.

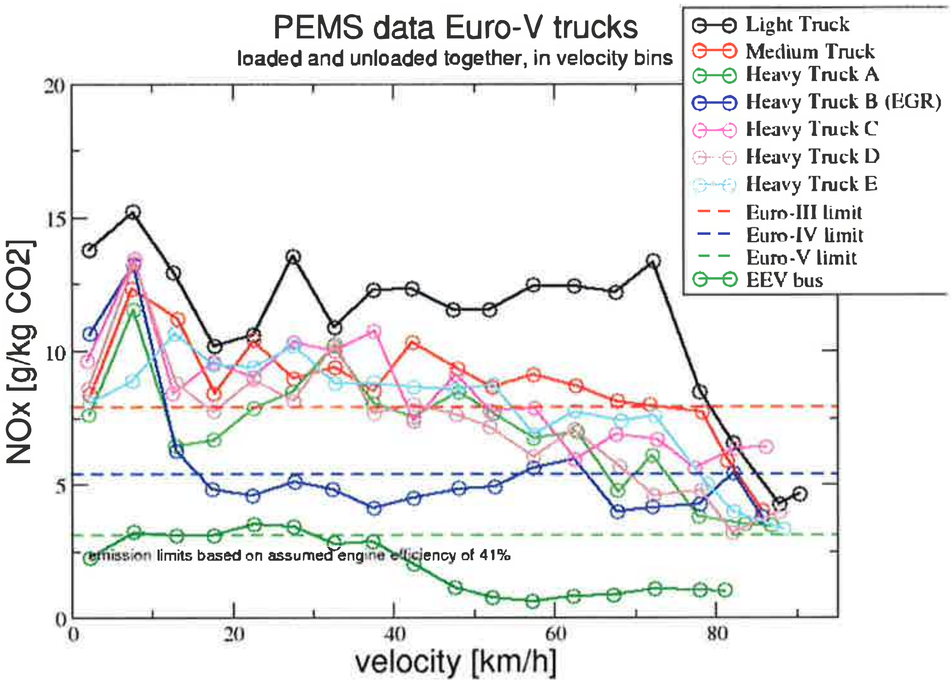
Figure 1; From pre Euro I engines going to Euro V engines the specific NOx emission and PM emission have reduced drastically over the legislative test cycle (ESC);



For the *real world emission* tests performed on vehicles with Euro V certified engines, performed with a portable emission measurement system (PEMS) in the vehicle on the road, another picture emerges;

- The NO_x emissions from trucks in common urban situations are around three times higher than the corresponding emission limit value and much higher than real-world estimates based on laboratory tests as well.
- Only at high velocities, like occurring on the motorway, the NO_x emission control seems to function well for most vehicles.
- Only one vehicle, a city bus, did perform very well under all conditions, including urban driving conditions.

Figure 2; The picture shows that under real world conditions for most vehicles only at high speeds the desired emission level of Euro V can be neared or met.



A gap seems to exist between the emissions measured over the type approval test and the real world emission as measured on the road;

- To reduce NOx emissions on Euro V engines highly efficient NOx control systems (SCR) are installed. But, if the conditions for an efficient operation are not met, the NOx emission can increase up to a level as seen without control system.
- The results highlight the need for including real world emissions in legislation beyond Euro V, not only controlling averaged emissions over accurately defined driving cycles, but also separately controlling for instance real world urban emissions

Within this programme it was not yet possible to investigate the durability of the NOx control systems. Furthermore, based on the data analyses of the data gathered in this programme, more insight in the real world emission performance of vehicles typically operating in urban areas, like small distribution trucks, busses, garbage trucks, etc is required. It is therefore recommended to follow up the testing programme with a focus on the real world performance of HD vehicles and give special attention to Heavy Duty vehicles operating in the urban environment and the durability of emission control systems.

Technical summary

This technical summary describes the goal, the context, the execution, the main conclusions and the recommendations of the programme. A further detailed explanation of the results is given afterwards in this summary.

Aim of the programme

This is the seventh report of the project In-Service Testing Programme for heavy duty vehicles and engines tail pipe emissions. This report presents the results and analysis of all tested vehicles and engines in the programme during the period 2006-2009.

This programme is carried out on behalf of the Dutch Ministry of Public Housing, Spatial Planning en the Environment (VROM). The goal is to produce an inventory of the exhaust emissions of heavy duty vehicles already in use for some period of time, and to compare the exhaust emissions with those of the type approval emission limits. The results of the investigation allow a better understanding of the developments regarding emissions of heavy duty vehicles under laboratory test conditions and in practice, serving the purposes of emission modeling, and form a basis for discussions on national and international level regarding the development of emission legislation.

In the EU, programmes like this one were initiated on a voluntary basis by Member States with a special interest to monitor the progress of in-service emission performance of heavy duty engines. This monitoring was done with the goal to see if emission legislation leads to improvements and the results were also used to bring issues with HD engines to the daylight to discuss them with the stakeholders, typically the manufacturer and the Type Approval Authority.

In the EU, a working group called Eurisec, was formed to join the interests of the national programmes of the Member States, to share experiences and to emphasize the urge for a formalized ISC checking system with real impact.

A recent change in emission legislation already made the typical role of the voluntary national programmes formal; results of such programmes should be used by the Type Approval Authority in judging the Conformity of vehicles In-Service. Besides this change, a newly developed measurement procedure using a portable emission measurement system (PEMS) will enable actual In-Service Conformity checking in real life on the road instead of in the laboratory. For this reason, this report also deals with measurements using the new in-service testing procedure based on PEMS; applying this new procedure in the Dutch national programme has drastically changed the programme during its course.

The In-Service Conformity procedure using PEMS already aims at Euro V engines be it that for these engines the PEMS method is only a screening tool and the engine test on the test bed remains decisive. It is expected that PEMS will be fully implemented as a stand alone tool for ISC checking as of Euro VI and it is the desire of the Dutch Ministry of VROM that the procedure is extended towards the checking of Off Cycle Emissions. This is to close the gap between the emission performance as obtained under strictly defined laboratory conditions and the emission performance as obtained under all representative real world conditions.

For the purpose of this inventory, vehicle owners are approached with the request to make their vehicle available for emission testing by TNO. The programme consists of a few parts:

- the In-Service Conformity concerning exhaust emissions is checked by means of an alternative procedure, based on the official EU ESC test cycle, but instead being performed on a engine, the test is performed with the engine in the vehicle, driving it on a chassis dynamometer,
- the In-Service Conformity concerning exhaust emissions is also checked by means of the recently in the EU developed PEMS procedure, measuring exhaust emission in the real world on the road.
- The emission data gathered in this measurement programme is used for national and international emission modeling purposes and HD emission working group discussions and
- ad-hoc questions regarding heavy duty emissions can be answered, sometimes by additional special testing.

The main themes for the additional and ad-hoc questions in this programme were:

- non regulated emissions (NO_2, NH_3 and N_2O)
- retrofit systems and test procedures for non road and in particular inland water way vessels
- retrofit particle filters

This programme aimed at Euro IV and Euro V engines as these engines are equipped with significant different technology to reduce exhaust emissions then ever before; examples are exhaust gas recirculation (EGR), systems for Selective Catalytic Reduction (SCR) and Diesel Particle Filters (DPF). Previous legislative categories have been reported in [Riemersma, 2009]. The Euro V engines are mainly from the period 2005-2009, meaning that mostly engines have been tested which were sold ahead of the implementation dates of Euro V. The early introduction of these engines was stimulated by foreign, national and local incentive programs. Euro V has several sub-stages, coded by letters, in which there are different requirements with respect to OBD and NOx control, see appendix D for a full table of Euro V stages.

Overall conclusions

Emissions of NOx and PM from HD vehicles have a considerable contribution to air pollution. At the moment, air quality limits are still exceeded in many cities. The main goal of EU emission legislation is to decrease the emissions of HD vehicles step by step. In the past, special procedures have been developed to test the emissions of engines types in the laboratory.

Performing these legislative emission test cycles in this In-Service testing Programme has shown that over time legislation has resulted in a decrease of the emissions of Heavy Duty engines over these test cycles; for Euro V (2009-2013) the NOx emission over an ESC test is at 30% and PM is at 5% of the level of Euro 0 (engines of 1990-1993).

Nevertheless, the vehicle emissions measured over the type approval cycle have decreased considerably whereas locally limits for air quality are still exceeded. A part of the problems can be explained by the economic growth and the increasing demand for transport, but this is not the only explanation. It will be shown in this report that the current legislative procedure, testing emissions in a laboratory may need a firm revision in terms of 'coverage'.

While a turn in emission reduction technology can be observed as of Euro IV (2005), where mainly EGR, sometimes in combination with PM catalysts dominated the market, Euro V can be regarded as the first generation where most manufacturers chose SCR to achieve a significant reduction of the NOx emission. An advantage is that the engine can be tuned towards a low FC and a lower PM emission as the SCR would reduce much of the increased NOx emission, the natural trade off of tuning diesel HD engines this way. Applying SCR, however, comes with the consumption of a reagent (urea or AdBlue) and therefore additional operational costs set back the benefits of the lower FC.

An SCR system typically operates best when its temperature rises above 200 ºC, only then reagent can be injected and NOx will be reduced. Current test procedures based on the ETC and ESC driving cycles only focus on warm engine operation and even have a high engine load distribution. Because of the high exhaust gas temperatures during these cycles, SCR systems should perform very well and are not challenged by more real world, low load and low exhaust gas temperature conditions. But maybe Euro V must be seen as a transition period where the technology can show its potential and its durability, its strengths and its weaknesses.

The results of the test programme, applying the steady state ESC test cycle, have shown that the In-Service PM emissions of Euro IV engines with EGR are very scattered and on average above the applicable limit. For NOx Euro IV engines perform somewhat better; on average for the engines tested the limit is only just exceeded. For Euro V engines the PM as well as the NOx are on average just above the applicable limit, be it with some scatter. Regarding the capabilities of SCR to reduce NOx Euro V engines are probably very critically tuned.

Outside the test cycle, in the real world, another picture emerges. Here a large share of the vehicles did not manage to produce results in the order of the ESC and ETC limit of 2,0 g/kWh. Some engine types just managed 2,0 g/kWh only under warm and high load driving conditions, like occurring on a highway. On average in the real world the NOx emission was about 3,4 g/kWh. But this is an averaged number in which e.g. emissions under urban operation are smoothened out due to the relative low contribution in terms of mileage. Under urban operating conditions and with zero or half the payload the vehicles perform around the level of Euro III engines, which is around three times higher than the applicable emission limit.

In this programme it became clear that a gap exists between the type approval emission performance and the real world emission performance. For the tested trucks this gap mainly exists at operation outside the highway and lower payloads seems to increase the problem. For some vehicles this gap even exists under conditions where it was expected that emissions easily would have been reduced to an agreeable level.

Therefore, the results highlight the need for including real world emissions in legislation beyond Euro V, not only controlling averaged emissions over accurately defined driving cycles, but also separately controlling for instance real world urban emissions.

Recommendations

- Due to the fact that real world NOx emissions fall short compared to formal requirements on type approval tests it is recommended to further investigate the real world performance of HD vehicles. This would contribute to a better understanding of the causes of the short-fall and would also be a basis for the discussions on the development of better test procedures for Euro VI and beyond.
- It is recommended to investigate the exact cause of the short-fall between type approval test and real world performance. This can be done by performing both tests on one vehicle.
- Based on the analyses of the data gathered in this programme, more insight on HD vehicles typically operating in the urban environment, like distribution trucks, busses, garbage trucks is required. A new programme should also aim at testing these types of vehicles in the real world using PEMS.
- The programme was not able to conclude on the durability of SCR systems. It is recommended to investigate the durability of such systems to gain a clear picture as to whether these systems are able to efficiently reduce NOx over the lifetime of a vehicle.
- It is recommended to investigating Remote Sensing as an option to monitor the emission performance of the fleet in-service. Reasons are the currently very selective sample, possibly not showing the worst vehicles and the need to monitor overall activity of emission reduction systems.
- When the new emission legislation for Euro VI comes into force PEMS data can be used in the legislative process, even for Euro V vehicles. If deemed necessary, in a future programme, PEMS data should be used for discussion with the Type Approval Authority and the manufacturer.
- It is recommended to perform an in-depth investigation in the functionality and the robustness of the Em-road tool and the pass-fail method which are currently proposed to analyze and asses the measured real world data. This investigation brings to the light what is and what is not included in the analyses and how much data is smoothed, hiding emission events under possible important driving conditions, like urban driving.
- Although NH_3 was measured under static conditions, it is recommended to measure the NH_3 slip under transient conditions.
- With the growing importance of CO_2 emission and the emerging need for a tool to determine the CO_2 emissions of HD vehicles, it is recommended to follow the developments of technology and legislation in this area. The same accounts for bio-fuels.
- With the non-road sector gaining relative importance in the contribution to air pollution it is recommended to follow the developments of technology and legislation in this area.

Detailed test results

In-Service Conformity (laboratory ESC tests)

For the performed In-Service Conformity programme steady state ESC type approval cycles were performed with the engine in the vehicle and the vehicle on a chassis dynamometer. The numbers of vehicles and engine types tested are shown in the table below:

Table 1; The number of vehicles and engine types measured in the period 2006-2009 over the ESC. In brackets the total number of the overall project.

Chassis Dynamometer ESC	Number of Vehicles	Number of tests per vehicle*	Number of Engine types
EURO IV	8	2	4 (Row B1)
EURO V	15	2	6 (Row B2, letter D)
Total	23	46	10

**In some cases more tests were performed*

The following table shows the amount of vehicles performing below or above the applicable TA limit. For NOx of both Euro IV and V only one engine type performs better than the limit. For PM the Euro V engine types perform equally above and below the limit. For Euro IV this is only one type. This type is equipped with a PM catalyst.

Table 2; overview of the amount of engine types performing below or above the applicable TA limits on NOx and PM, over the ESC test.

	NOx > limit	NOx < limit	PM > limit	PM < limit
Euro IV	3	1	3	1
Euro V	5	1	3	3

The group of **Euro IV** engines, all with EGR (Exhaust Gas Recirculation), seems to have a problem with the in-service PM emission, with exception of one engine type which is also equipped with a PM-Kat to reduce the PM emissions. On average the group of Euro IV engines just exceeds the NOx limit but clearly exceeds the PM limit by more than 100%. The PM problem can possibly be related to the typical emission reduction strategy used. EGR is known to possibly trade-off a NOx reduction for a PM increase, which shows when no additional aftertreatment like a particle filter is placed to reduce the PM emission. One vehicle also had a high oil consumption which might also have caused a high PM emission. For the tested vehicles, considering both NOx and PM, the strategy did not succeed in reducing either of the components to an agreeable level of the in-service emissions below the respective limits.

The group of **Euro V** engines did perform somewhat better than the group of Euro IV engines. All tested engine types have an SCR (Selective Catalytic Reduction) system to reduce the NOx emission. But although this type of exhaust gas aftertreatment is capable of greatly reducing the NOx emission, especially under the warm test conditions of an ESC, the engine types just perform above the limit with exception of one type which performs just better than the limit.

Considering the typical trade-off of this type of emission reduction strategy between NOx emission on the one hand and urea consumption and fuel consumption on the other hand, the engines seem to be very critically tuned towards low fuel and urea consumption at the cost of a very critically tuned or sometimes even clearly exceeding NOx. It did not become clear whether ageing of the SCR catalyst might have caused a part of the problems.
On the NOx points or 'mystery points', the three random points that are tested between the fixed load points of the ESC, one vehicle had clearly too high NOx emissions, all three engines of the same type clearly exceeded the limit for these random NOx points.
For PM there is a spread between engine types of different manufacturers, but on average the Euro V vehicles perform just on the limit.

The Euro V engines seem to be very critically tuned with regard to both NOx and PM, in some cases leading to in-service emissions exceeding the NOx or the PM limit, or both.

Real world emissions (PEMS)

In 2009 a special programme was started using a PEMS (Portable Emission Measurement System) for measuring the gaseous exhaust emissions of HD vehicles on the road. A procedure using PEMS is developed in the EU PEMS Pilot Programme especially for the purpose of In-Service Conformity testing. In the next table the amount of vehicles tested with PEMS are shown.

Table 3; The number of vehicles and engine types measured in the period 2009 using PEMS

PEMS	Number of vehicles	Number of Engine types
EURO V EEV	2	2
EURO V	7	7

With a PEMS two types of trips were driven;

1. a representative trip as this is required in the official EU technical procedure for PEMS, at the moment being developed for Euro V engines. The results are evaluated by means of a special pass-fail method.
2. a reference trip, which is every time the same trip around Helmond-Eindhoven. This trip covers a wide range of driving conditions (motorway, city-centre, constant speeds, sub-urban, etc. The data from this trip is mainly used for modelling purposes.

With respect to PEMS as a tool to measure emissions the following conclusions can be drawn;

- the gaseous emissions and the fuel consumption can be measured with PEMS with sufficient accuracy
- PEMS delivers a huge amount of 'real world' emission data per vehicle under representative, transient driving conditions and gives insight in a vehicles emission behaviour under the different driving conditions
- as such PEMS is a useful tool for gathering emission data for the purpose of emission modelling.
- the reproducibility of PEMS is limited. For instance, traffic and the ambient conditions change over time and driving behaviour is not defined. This makes it hard to make e.g. back to back comparisons between vehicles.
- concerning workability PEMS can not be regarded as a plug and play tool for emission scanning, screening or testing; mounting PEMS on a vehicle, measuring with PEMS and working out the data can be qualified as high level, technical work were the experience should be on the same level as would be required for emission testing in a laboratory
- a procedure to measure PM, particulate matter, is still under investigation. The candidate systems for PM will make the complete PEMS system more complex.
- PEMS seems a suitable tool to measure the emissions for an In-Service Conformity procedure, although the procedure starts to become rather complex, especially when the measuring method for particulate matter is included.

With respect to the pass fail method as developed for Euro V In-Service Conformity checking, the following conclusions can be drawn;

- the pass fail method, using windows to average the data, does not seem to be very robust. The results largely depend on the driving characteristics during the window and in advance of the window. As such, conditions can optimised for obtaining the best results.
- the pass fail method is developed after Euro V entered into force. Therefore, Euro V engines can not become illegal by applying the new procedure. For Euro V PEMS and the accompanying pass fail method must be regarded as a screening tool to see if an engine in a vehicle, operated on the road, produces similar results as required for Type Approval over an ETC. The proposed pass fail limit is 1,5 times the ETC limit. For NOx this comes down to 3,0 g/kWh. For Euro V an engine test on a test bed remains decisive for proving non-conformity.
- the method to derive engine power from the ECU is not very accurate, or at least no specifications have been defined for this accuracy. This makes the emission result in g/kWh rather uncertain as the kWh value fully relies on the output of the engines computer. An option would be to use the CO_2 method, where the emission result is related to CO_2 instead of work. It has already been shown that for the CO_2 method low loads do not need to be excluded from the data. The importance of also testing low load operating condition has already been shown earlier in this summary.

According to the currently proposed technical PEMS procedure and applied pass fail method the following conclusions can be drawn:

- one vehicle out of seven vehicles, a bus, performs consistently below the pass fail limit of 3,0 g/kWh for NOx. Two others perform on average just above this limit and the rest performs substantially higher, often with a large scatter in performance.
- most of the scatter is produced by the typical trip conditions over which the emissions are analysed. Trips with a lot of low load operation result in high NOx values.
- two vehicles showed remarkably high NOx emissions.
  - one vehicle did not perform well on the motorway and showed values of around 4 to 5 g/kWh, even though the thermal conditions were there to reduce the NOx significantly.
  - the other vehicle, a Euro V EEV, probably has a problem with the SCR system. It hardly reaches temperatures were NOx can be reduced effectively. This vehicle showed emissions of 5 to more than 8 g/kWh of NOx.

With respect to the real world emission performance as measured with PEMS the following conclusions can be drawn;

- The NOx emissions from trucks in common urban situations are around three times higher than the corresponding emission limit and much higher than real-world estimates based on laboratory tests as well.
- Only at high velocities, like occurring on the motorway, the NOx emission control seems to function reasonably well for most vehicles.
- Only one vehicle, a city bus, managed to perform very well under typical urban driving conditions.

Special cases

One Euro IV engine with a PM catalyst, tested over the ESC, had a very high PM emission, exceeding the applicable limit. According to the manufacturer this would be caused by sulphur from the fuel and particles deposited in the exhaust system during low load operation in the history of the vehicle. Retesting the same vehicle with high load preconditioning lead to a decrease of the PM emission, but still the vehicle did not perform very well on PM. Testing another type of the same brand with the same type of PM catalyst resulted in a much better result with PM values around the limit.

One Euro IV engine had a high oil consumption, which might have contributed to the higher PM emission. For the same engine type a remarkable strategy was discovered. The EGR was shut off when the ambient temperature sensor measures 5-8 °C. This resulted in very high NOx emission of 9,0 g/kWh and a lower brake specific fuel consumption. The Type Approval Authority was informed.

One Euro V engine had a clogged urea dosage system, resulting in a very high NOx emission of 7,0 g/kWh. The vehicle received a hardware and a software upgrade and performed well afterwards. The Dutch importer said to organize a search and recall action to find the last vehicles which could have missed the upgrade.

One Euro V engine showed high NOx peaks during some mode points. It appeared that when the engine was not running stable the ECU shuts the reagent injection off intermittently. No explanation was given by the importer for this phenomenon and no cause was found at the vehicle.

NO_2

Air quality limits have been set for NO_2 because NO_2 is more toxic than NO. For local hot spots the NO_2 emissions are often at a critical level or exceeded. For tail pipe emissions, there is only a limit for NOx, the sum of NO and NO_2. Because the fraction of NO_2 in the sum of NO and NO_2 is very important for air quality and air quality calculations are based on emission models the tail pipe NO_2 emission has been measured during the entire programme.

For most Euro IV and V engines the NO_2 fraction is very low and ranges from 1 to 10%. For aftertreatment technologies applying an oxidative component with platinum higher levels of the NO_2 fraction were observed. For instance, a CRT continuous regenerating particle trap has a high NO_2 fraction in the range of 30-45%, the values varying with driving condition. Also for the PM-kat higher fractions of NO_2 were observed, for this type of particle filter as used by MAN NO_2 fractions from 30 to 70% were observed.

For the engines with an SCR catalyst the NO_2 fraction is generally very low in the order of a few percent. However, if the after treatment system with an SCR also contains an ammonia oxidation catalyst, an oxidative component down stream of the SCR catalyst, higher fractions of NO_2 were observed. In some cases at idling, fractions reach as high as 60%. On average Euro V engines with an AMOC showed an NO_2 fraction of 15% over the ESC cycle.

NH_3

During the steady state test conditions of the ESC the NH_3 emission or the so-called NH_3 slip was well under control. Results over the ESC varied from 1 to 13 ppm. Only one vehicle showed values just above 25 ppm, but only for a few of the 13-mode points. It must be remarked that steady state test conditions are not very challenging. For dynamical operation of the engine it is harder to optimize reagent dosage, keeping NH_3 slip low.

N_2O

The N_2O concentrations measured were very low and only just above the detection limit of the instrument used. As N_2O has a high Global Warming Potential of around 300 the low concentrations still add another 0,5 to 1,0 % of CO_2 equivalent to the green house gas emissions of the engine.

Contents

Appendices

1 Introduction

This is the seventh report concerning the project “In-use Testing Programme on Heavy Duty Vehicles”. The first report contained the results of the pilot [Bijsterbosch , 1993]. Subsequently, three reports have been published with the results of the period 1994-1995 [Bijsterbosch, 1995], the period 1996-1997 [Rijkeboer, 1999], and the period 1998-2000 [Riemersma, 2000]. Then, two reports were published with the results of Euro III vehicles; one interim report of vehicles measured until the year 2004 [Riemersma, 2006] and one final report which includes all the measured Euro III vehicles until 2006 [Riemersma, 2009].

The present report concerns the period 2006-2009 and is mainly focused on vehicles with Euro IV and V technology.

Road vehicles, trucks included, receive a type approval by measuring exhaust gas emissions of a prototype that is supplied by the manufacturer for this certification. It concerns the emission of carbon monoxide (CO), total hydro carbons (THC), nitrous oxides (NOx) and particulate matter (PM).
So as to guarantee that production vehicles also comply with the applicable requirements, the relevant Directives (2005/55/EC and 2005/78/EC) contain paragraphs that regulate the conformity of production (CoP). According to its clauses, vehicles or engines from the production may be checked when they come off the production line (whether or not after a suitable running-in period).
Furthermore, a paragraph in the Directive 2005/55/EC referring to ANNEX III of 2005/78/EC, regulates the In-Service Conformity; From 1 October 2005, for new types, and from 1 October 2006, for all types, type-approvals granted to vehicles shall also require confirmation of the correct operation of the emission control devices during the normal life of the vehicle under normal conditions of use (conformity of in-service vehicles properly maintained and used)

As the emission legislation becomes more stringent, it becomes more important to monitor if the requirements are really met by vehicles in the field, and not only by carefully optimized type approval ones. Maintaining the emissions in the field is becoming more important than a first demonstration of the emission performance of a Type (Type Approval). Hence some Member States (the Netherlands included) already perform an in-service testing programme, or “in-service conformity” testing, in anticipation of a European legislation on this point.

In the Netherlands the Ministry of the Environment (VROM) started in 1987 to monitor emissions from passenger cars in-use, followed in 1994 by a similar monitoring of trucks, the project “In-use Compliance Programme Trucks”. Additionally, the project serves to collect actual fuel consumption and emission data (CO_2 included) from trucks in Dutch traffic, the collected data for reliable calculations for emission inventories. The importance of reliable emission factors has increased over recent years, since more and more policy decisions have to be taken on the basis of the environmental performance of traffic.

In-Service testing (laboratory ESC tests)

Within the In-Service Testing programme it is checked if the emissions of vehicles put into service do comply with the same requirements as vehicles that come off the production line of the manufacturer. Initially, this check aimed at compliance with the requirements of the so-called SELA-scheme, a Netherlands fiscal incentive for vehicles that showed an early compliance with the requirements of future emission limits. However, that aspect was no longer an issue during the period reported here.

Since the main objective of the project is the monitoring of emissions from vehicles in use, the measurements have been performed on relatively young vehicles, fitted with a EURO IV or V engine. The vehicles are borrowed from users who are mailed, and asked to put their vehicle at disposal voluntarily at a financial compensation.

In the case of heavy duty vehicles the type approval concerning exhaust gas emissions is performed on an engine that is not mounted in a vehicle. For that reason the type approval certification concerns the engine and not the vehicle. Since in the case of borrowed vehicles it is undesirable to take an engine out of the vehicle to install it on the engine test bed, TNO has, on request of the Ministry of the Environment, developed a methodology to test the engine while it is still installed in the [Gompel, 1993] updated with Jordaan, 2000]. The vehicle is placed on a chassis dynamometer and runs against a load provided by a brake coupled to the rollers. The engine torque needed to run the various test points is recalculated into a traction force on the rollers, by means of empirically derived formulae for the power losses in the driveline and the tyres. The formulae for the determination of the power losses are regularly verified, since with the progress of technology these losses continuously improve. This verification is performed by means of a correlation check, in which an engine is tested both on the engine test bed and on the chassis dynamometer (in a vehicle). Through the use of this simplified test methodology the duration of the measurement programme remains limited to one week per vehicle.

The complete run of the test is shown in the flow chart in [Riemersma 2000] and [Riemersma 2006]. The vehicle is checked for the correct specifications on reception. Then a first exhaust gas emissions test is made (ESC test). Subsequently, the adjustments and maintenance are checked. When any shortcomings are found, they are corrected after the first test and subsequently a second test is made in a correct state of tune. In the past programmes, when no second test was found necessary, in a number of cases 18 additional points of the engine map were measured. This was done in order to generate a more detailed input for the Artemis emission model, and also to gain a better insight in the emissions outside the regulated area of the ESC cycle. In EU international collaboration programmes the testing of static load points was abandoned for Euro IV and Euro V as for these emission stages real world and transient emission behavior became more and more important.

In the Netherlands In-Service Testing programme an additional ESC test was performed anyway. This was found necessary due the variability noted for both the NOx and the PM results. In some cases points outside the ESC area were measured, not for modeling purposes, but just for checking the emission behavior of the engine in a more complete range of the map.

In-Service testing (on-road PEMS tests)

In the EU within the PEMS Pilot Programme a procedure is being developed for testing the In-Service Conformity of engines installed in vehicles on the road using a Portable Emission Measurement System. At the end of 2008 for the Dutch programme it was decided to leave the method simulating the ESC on a chassis dynamometer and to start using the procedure as developed in the Pilot Programme, so as to gain experience with PEMS, a tool for checking the In-Service Conformity. Additionally, the data form the PEMS testing has been introduced in the PEMS working group to feed the discussions within the group and the PEMS data has lead to an even better understanding of the real-world emission behavior of Vehicles In-Service.

At the time of writing, the PEMS method, see above, has evolved in a technical procedure able to test the gaseous emissions. For PM no choice regarding the required system set up has been made.

The PEMS method is rather different from laboratory testing. Differences can be noted for reproducibility, repeatability, robustness, workability and more. Especially repeatability and reproducibility are lacking compared to lab testing due to effects of meteo, traffic, the driver etc.

But there are some advantages too. PEMS delivers real world data, under real world circumstances. When trips are selected with care, most traffic situations can be covered to find out all about emission behavior under a wide range of conditions. When a representative trip is driven, emission data can become representative for a certain application or usage (e.g. bus line 77).

An important goal of the PEMS tests performed in this programme was to gain experience with the PEMS equipment and the data gathered with this system. But next to ‘experience’ it delivered great insight in emission behavior of HD vehicles under real world driving conditions and it contributed to discussions on EU level in the EU PEMS workgroup, which deals with the development of PEMS as a legislative tool for checking In-Service Conformity.

With most vehicles both a reference trip as well as a representative trip was driven. The reference trip is every time the same trip, hence the name reference, and includes almost all traffic conditions as well as special conditions like idling, a coast down etc. For the representative trip the vehicle is operated as in the real world, following distribution routes, bus lines or whatever trip is typical for the vehicle. This is prescribed in the EU PEMS technical procedure and is being proposed as requirement for testing Euro V engines In-Service. For this procedure the required pay load is 50% of the max pay load and in a few cases, more or less payload was applied to experience possible differences in emission behavior caused by this pay load.

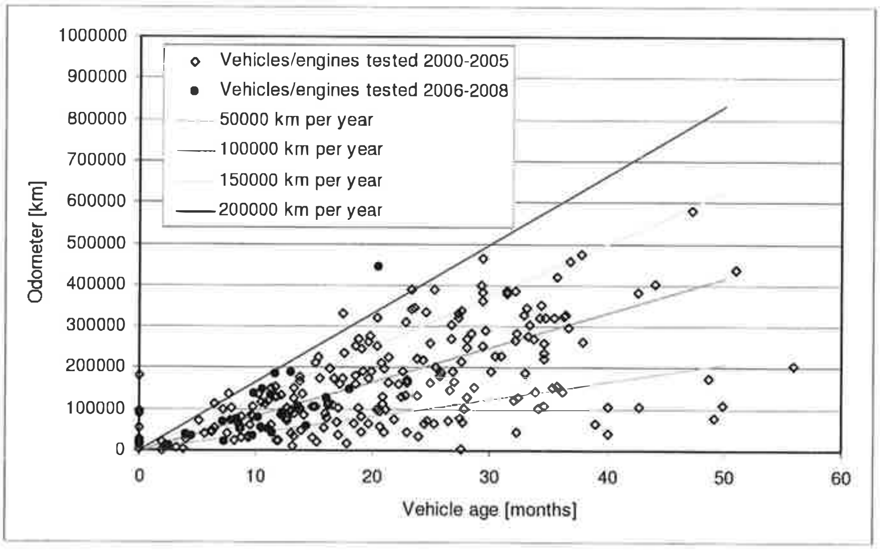
Engines and vehicles tested

The number of vehicles and engine types tested in the entire programme is shown in Table 1.1. The bold numbers show the numbers of Euro IV and V engines and vehicles tested in the period reported here. The Euro III engines tested during this programme have been added to the results of the previous report [Riemersma, 2009] issuing Euro III engines so that that report covers emission legislation exclusively up to Euro III and this report covers exclusively Euro IV and V. In total 279 vehicles have been tested, divided over 106 different engine types.

Table 4; *The number of vehicles and engine types measured in the whole programme so far. The bold numbers show the numbers of only Euro IV and V tested in the period reported here. The Euro III engines were added to the previous report [Riemersma, 2009].*

Class	Number of Vehicles	Number of Engine Types
EURO 0	26	10
EURO I	77	28
EURO II	86	29
EURO III	58	20
EURO IV	**8**	**4**
EURO V	**15**	**6**
EURO V Pems	**7**	**7**
EURO V EEV Pems	**2**	**2**
Total	279	106

Figure 3; mileage of the tested vehicles over vehicle age.



Additional programmes and testing

With a standard programme running ESC tests on a chassis dynamometer and at a later stage also running PEMS testing on the road it is easy to add more testing on the same truck to answer specific or ad-hoc questions. Also other testing than on the trucks and even consultancy can be added to the programme. The main themes for the additional and ad-hoc questions in this programme were:

- retrofit particle filters for HD vehicles and vans.
- retrofit systems and test procedures for non road and in particular inland water way vessels
- non regulated emissions (NO_2, NH_3 and N_2O)

2 In-Service Testing

2.1 Laboratory (ESC)

2.1.1 Vehicle selection

Appendix A gives a total overview of all engine types and vehicles selected for the In-Service Testing programme for Trucks of the period 2006-2009. In this chapter the selection is further explained.

In the selection of the engine types to be tested the aim has been to reflect as well as possible the vehicle fleet in the Netherlands. In that context the following criteria have been applied:

- Each time a selection is made, it is based on the sales statistics of the preceding two years, as supplied by the RDC, RAI data Centre through the RDW.
- From the sales statistics the best selling vehicle brands and engine types are determined.
- Exclusively vehicles with Euro IV and V engines have been selected.
- In principle the best selling engine types are eligible for selection. Additionally, the aim is at a distribution over the manufacturers as broad as possible.
- When the selection criteria would result in more than one type of the same manufacturer, in certain cases one of these has been replaced by the best selling type of a make that did not figure in the selection.
- As far as possible a wide range of engine powers is selected.
- Due to limitations concerning the test on the chassis dynamometer exclusively trucks with an engine power less than 350 kW are selected.

For the programme the sales statistics of 2006 and 2007 were used.

Table 5 shows for the 7 best selling makes how the market share of newly sold vehicles over the period 2006-2007 was distributed in the Netherlands. Additionally, the distribution per brand over the legislative classes Euro IV and Euro V is given. Although Euro V comes into force in 2009 already in the period 2005-2007 the fleet of newly sold vehicles consists of a large share of vehicles with Euro V engines. These engines are sold stimulated by national, local and foreign incentive programs. Within Euro V (Row B2) there are several different stages with different requirements with respect to OBD and NOx control. The different stages are coded by letters, generally displayed as part of the European type approval number.

Table 5; sales distribution (market share) of newly sold vehicles in the Netherlands over the period 2006-2007

	Brand	Euro IV	Euro V
DAF	32%	3%	30%
Scania	18%	13%	6%
Volvo	16%	2%	15%
Mercedes Benz	13%	4%	8%
MAN	12%	12%	0%
Iveco	4%	1%	3%
Renault	2%	1%	2%
Rest	2%	1%	1%

The engines selected with their specifications can be found in appendix A.

2.1.2 *Test procedure*

In the case of heavy duty vehicles the type approval concerning emissions is performed on an engine that is not mounted in a vehicle but on an engine that is mounted and operated on an engine test bed. For that reason the type approval certification concerns the engine and not the vehicle. Since in the case of borrowed vehicles it is undesirable to take an engine out of the vehicle to install it on the engine test bed and the installment of modern Euro IV and V engines with lots of electronics and an after treatment system on an engine test bed becomes time consuming, complex and expensive, TNO has, on request of the Ministry of the Environment, developed a methodology to test the engine while it is still installed in the vehicle [Gompel, 1993] updated with [Jordaan, 2000]

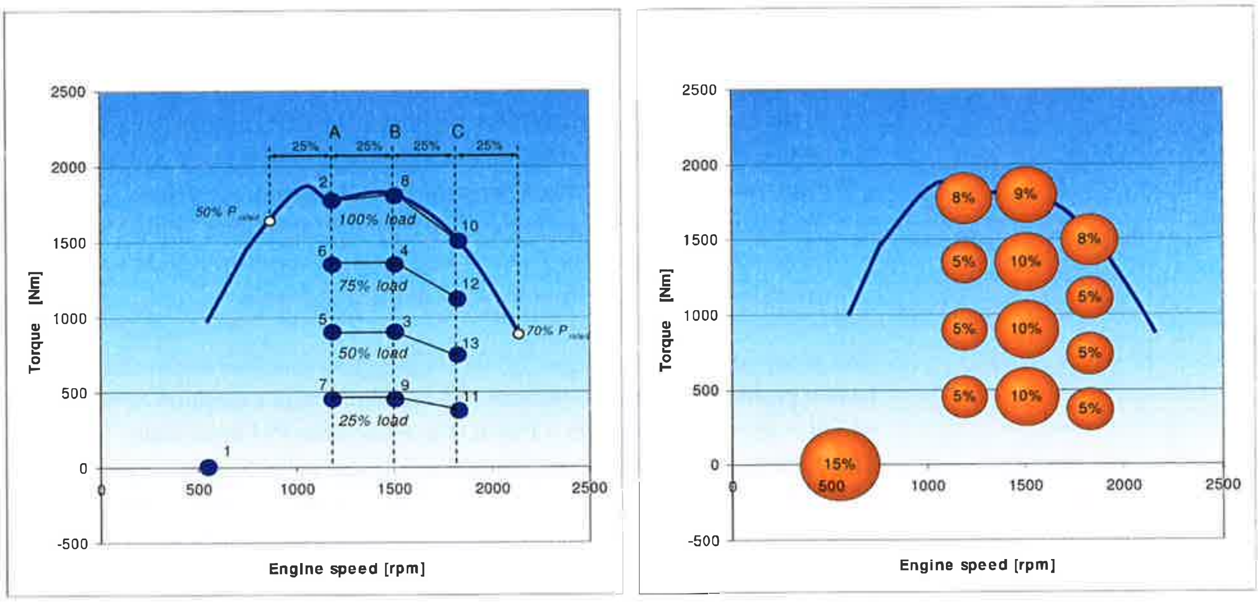
The vehicle is placed on a chassis dynamometer and runs against a load provided by a brake coupled to the rollers. The engine torque needed to run the various test points of the ESC is recalculated into a traction force on the rollers, by means of empirically derived formulae for the power losses in the driveline and the tyres. The formulae for the determination of the power losses are regularly verified, since with the progress of technology these losses continuously change. The verification is performed by means of a correlation check, in which an engine is tested both on the engine test bed and on the chassis dynamometer (in a vehicle).

Before the actual ESC tests, when a vehicle is installed on the chassis dynamometer, another check is performed to see if the empirical formulae have lead to the right settings of the loads. The check consists of two parts;

1) A net power check against the values supplied by the manufacturer and a
2) lambda check were the measured brake specific fuel consumption is checked against values supplied by the manufacturer.

After these checks and checks of the vehicle and engine general condition the vehicle is tested over the ESC twice. The duplicate test is necessary because of the decreasing emission values which affect the repeatability of the tests; the repeatability became relatively higher at Euro V emission levels. Especially for PM the test to test variation (repeatability) has become relatively larger. This has been investigated by testing one vehicle multiple times over the ESC test. This was reported in [TNO 2008; Q3] and it is also summarized in paragraph 3.7 It was concluded that for the equipment used, the repeatability (test to test variation) of the PM results amounts 15 to 20% whereas the reproducibility (lab to lab variation) can be bigger and probably amounts up to 30-40%. These values for the test variations have to be taken into account when considering the ESC results.

Figure 4; the steady state ESC cycle with on the left the definition of the load points and on the right the weighting of the individual load points to arrive at an overall ESC result



2.1.3 Results ESC:Euro IV and Euro V

All results of the ESC tests of the Euro IV and Euro V engines are presented in the pictures below, showing the results of the PM and NOx emissions against the respective Euro IV and Euro V ESC limits. All results per engine are presented in tables in the Appendix B.

The next picture shows the averages of all engines types of one emission class.

The results of CO and HC are presented in the Annex B dealing with the separate engine types. In general the CO and HC emissions of diesel fuelled Euro IV and Euro V HD-engines are low and well below their respective limits.

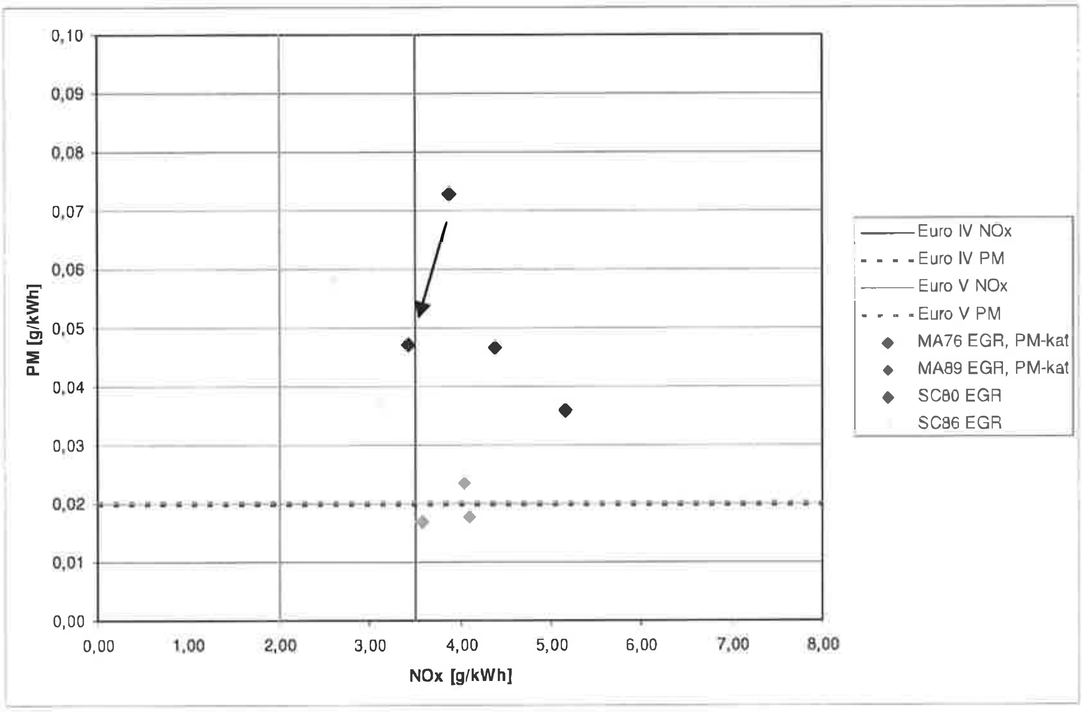
Concerning the **Euro IV** engines;

- Three engine types out of four have PM emissions which are clearly higher than the Euro IV ESC limit of 0,02 g/kWh, exceeding the limit by around 80 to 250% for individual engines, but from 100 up to 200% for engine types averaged. In one case the high PM emission could be related to a high oil consumption (SC80_1).

- The engine type having the lowest PM emissions is equipped with a PM-kat but another vehicle with a PM-kat has the highest PM emission. The results of this engine were examined by the manufacturer. A share of the high PM emission, about 0,015 g/kWh, of this engine can probably be related to a high sulphur content of the fuel the engine operated on in-service. According to the manufacturer the remaining excess PM emission could be caused by PM release of the PM-kat or by contamination in the measurement system itself. In an additional investigation TNO has looked at repeated PM tests on one engine to investigate the possible effects see paragraph 3.7.
- In the case of one type the NOx limit of 3,5 g/kWh is clearly exceeded, by 36% for engine types averaged. One other engine type has NOx emissions just exceeding the limit, while two other types perform around the limit or below.
- No engine type performs better than both the applicable limits for NOx and PM.
- On average the group of Euro IV engine just exceeds the NOx limit but clearly exceeds the PM limit by somewhat more than 100%.

The group of Euro IV engines, all with EGR (Exhaust Gas Recirculation), seems to have a problem with the in-service PM emission, with exception of one engine type which is also equipped with a PM-Kat to reduce the PM emissions.
The NOx emission of the group is better, but still on average above the limit.
The PM problem can probably be related to the typical emission reduction strategy used. EGR is known to possibly trade-off a NOx reduction for a PM increase, which shows when no additional after treatment like a particle filter is placed to reduce the PM emission. Considering both NOx and PM, the strategy did not succeed in reducing either of the components to an agreeable level of the in-service emissions below the respective limits.

Figure 5; The results of the ESC tests of the **Euro IV** engines. The points are averages of two consecutive ESC tests. One vehicle that clearly exceeded the PM limit was examined by the manufacturer and was tested again after examination. The arrow indicates the emission performance before and after examination.



Concerning the **Euro V** engines;

- One Euro V engine showed a very high NOx emission when compared to the applicable limit. This vehicle was send to the manufacturer for inspection and had software as well as hardware replaced. At the second test run the modified engine and another selected engine of the same type performed much better, but still just around the applicable limit (see the arrow). For this engine type a recall action was done by the Dutch importer.
- The other types performed better on NOx, but still some engines exceed the PM limit by 50 to 100%.
- Per engine type the NOx emissions exceed the limit up to 30% and up to 50% for PM.
- No engine type performs better than both the applicable limits for NOx and PM.
- On average the group of Euro V engines just exceeds the NOx limit. The group performs almost spot on the PM limit.
- Two out of six engines types performed well on the random NOx points. One engine type did exceed most random NOx point checks. The other engine types had only one or two points exceeding but in most cases only with low percentages.

The group of Euro V engines did perform somewhat better than the group of Euro IV engines. All tested engine types have an SCR (Selective Catalytic Reduction) system to reduce the NOx emission. But although this type of exhaust gas after treatment is capable of greatly reducing the NOx emission, especially under the warm test conditions of an ESC, the engine types just perform above the limit with exception of one which performs just better than the limit.

Considering the typical trade-off of this type of emission reduction strategy between NOx emission on the one hand and urea consumption and fuel consumption on the other hand, the engines seem to be very critically tuned towards low fuel and urea consumption at the cost of NOx.
It must be remarked that the NOx emissions of this programme -applying the specific test method of testing an engine in a vehicle on a roller bench instead on an engine test bed- might be slightly biased due to the specific test method. The thermal situation of an engine in a vehicle is different than the thermal situation of an engine on an engine test bed. Possibly the engine and the intake air get warmer and hence, the NOx emissions might have increased a bit.
For PM there is a spread between engine types of different manufacturers, but on average the Euro V vehicles perform just on the limit.
The Euro V engines seem to be very critically tuned with regard to both NOx and PM, in some cases leading to in-service emissions exceeding the NOx or the PM limit, or both.

Figure 6; the results of the ESC tests of **the Euro V** engines. The points are averages of two consecutive ESC tests. One Euro V vehicle clearly exceeded the NOx limit. This vehicle was examined by the manufacturer and tested again after an update with hardware and software; the arrow indicates the emission performance before and after the update.

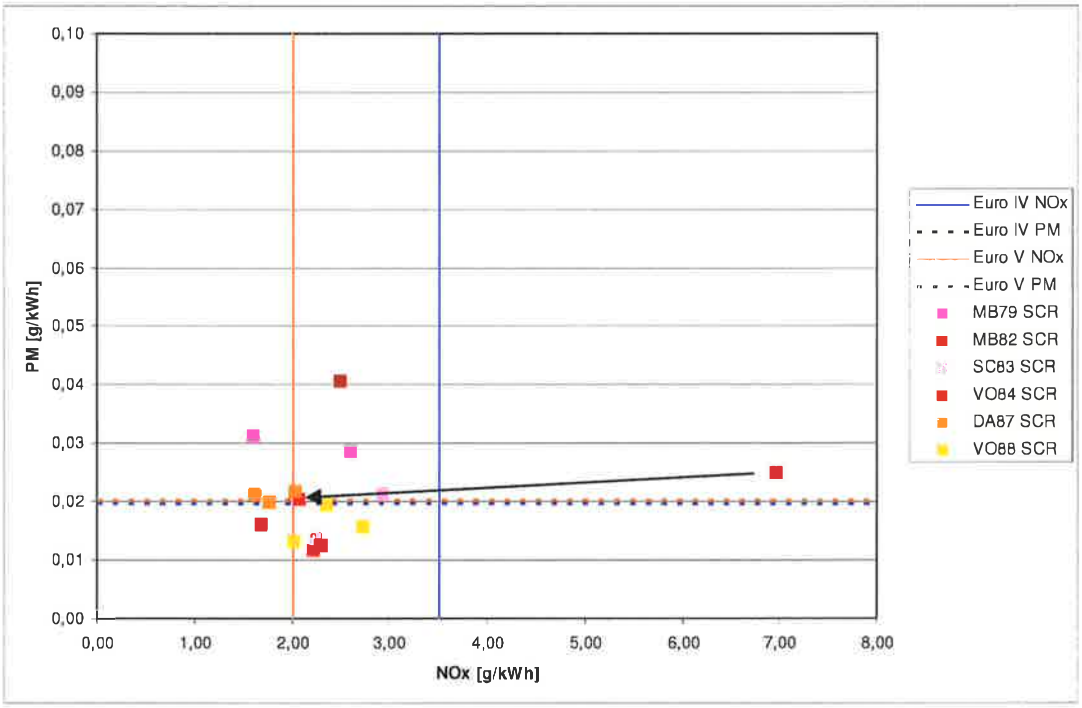


Figure 7; the results of the ESC tests of the **Euro IV and the Euro V** engines. The points are averages of all engines of a type. The '+'symbols represent the average of respectively the Euro IV and the Euro V group.

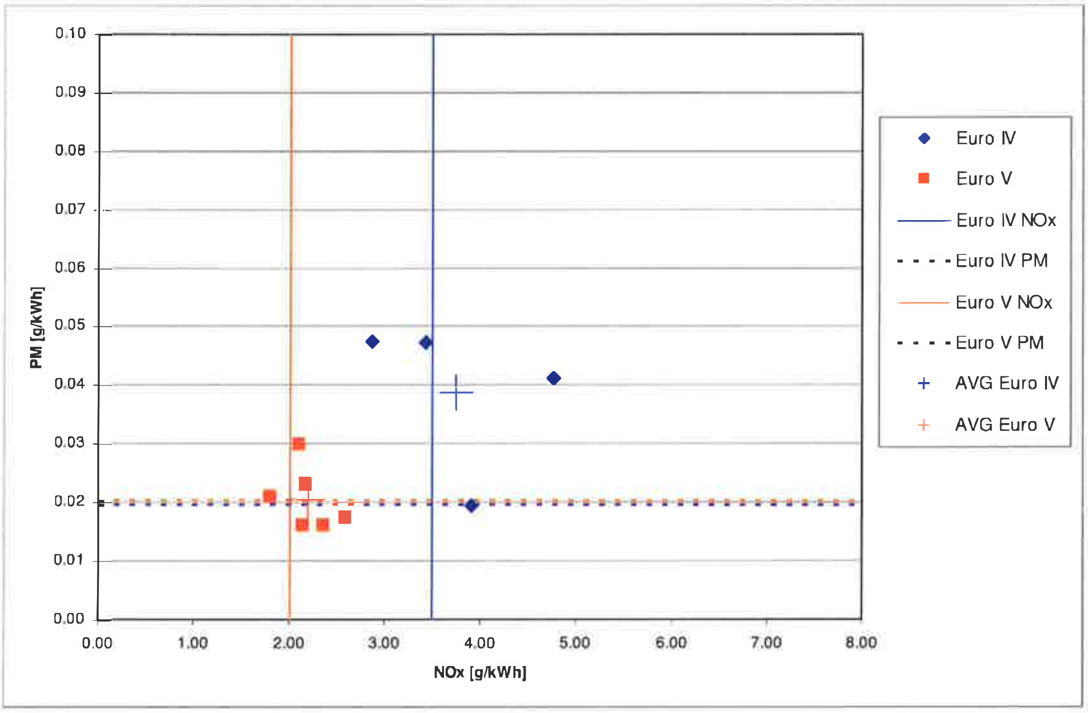


Table 6; overview of the amount of engine types performing below or above the applicable TA limits on NOx and PM, over the ESC test.

	NOx > limit	NOx < limit	PM > limit	PM < limit
Euro IV	3	1	3	1
Euro V	5	1	3	3

2.1.4 *Results ESC; from Euro 0 to Euro V*

With an in service testing programme running over more than a decade trends can be revealed with respect to the emission performance over the steps in emission legislation. Below a picture is shown with all measured vehicles/engines, the vehicles arranged by legislative category. Furthermore, the average of each legislative category is given.

Going from Euro 0 to Euro V the picture clearly shows a trend towards lower PM and NOx emissions and, with the exception of a few outliers, the scatter of each category becomes smaller as well.

Figure 8; the progress of HD engine emissions of PM and NOx as measured over the ECE R49 test (for Euro 0 to Euro II) and the ESC test (for Euro III tot Euro V)

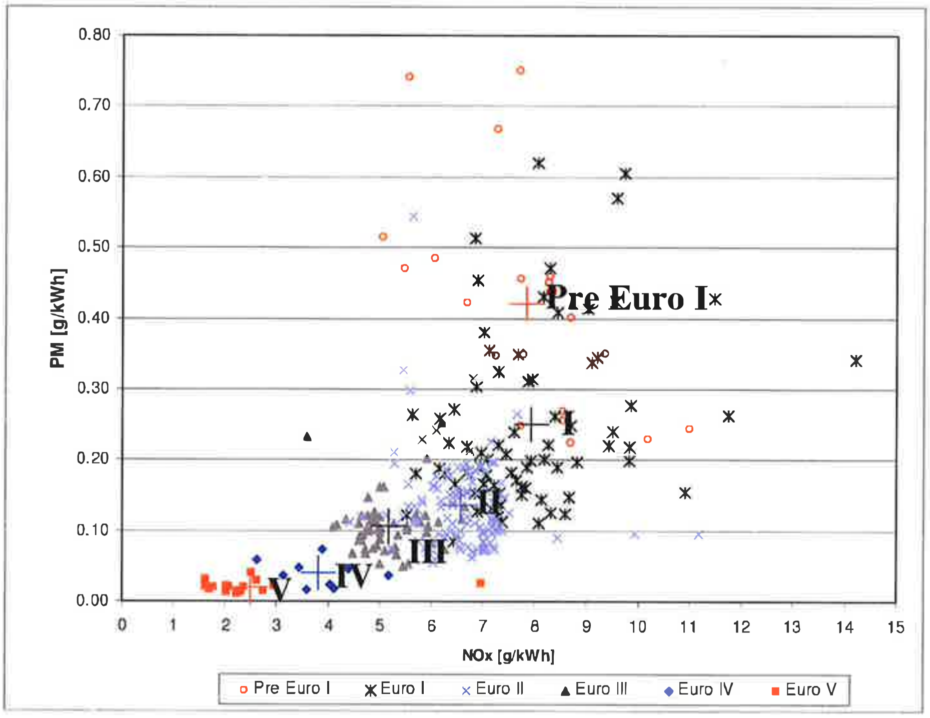


Figure 9; the progress of HD engine emissions of **NOx** as measured over the ECE R49 test (for Euro 0 to Euro II) and the ESC test (for Euro III tot Euro V). The red stripes represent the applicable limits, the black line the trend of the average.

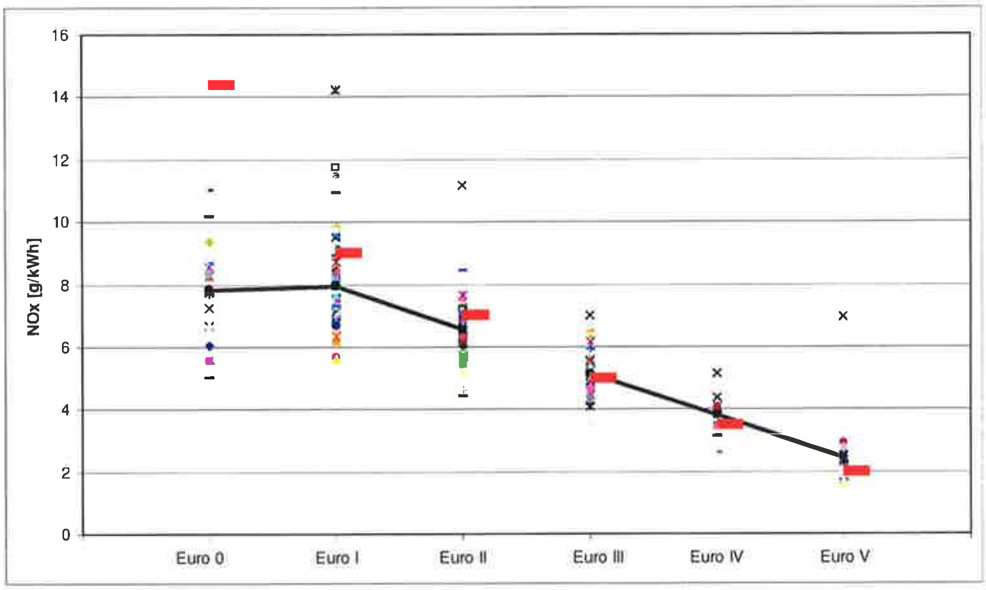


Figure 10; the progress of HD engine emissions of **PM** as measured over the ECE R49 test (for Euro 0 to Euro II) and the ESC test (for Euro III tot Euro V). The red stripes represent the applicable limits, the black line the average.

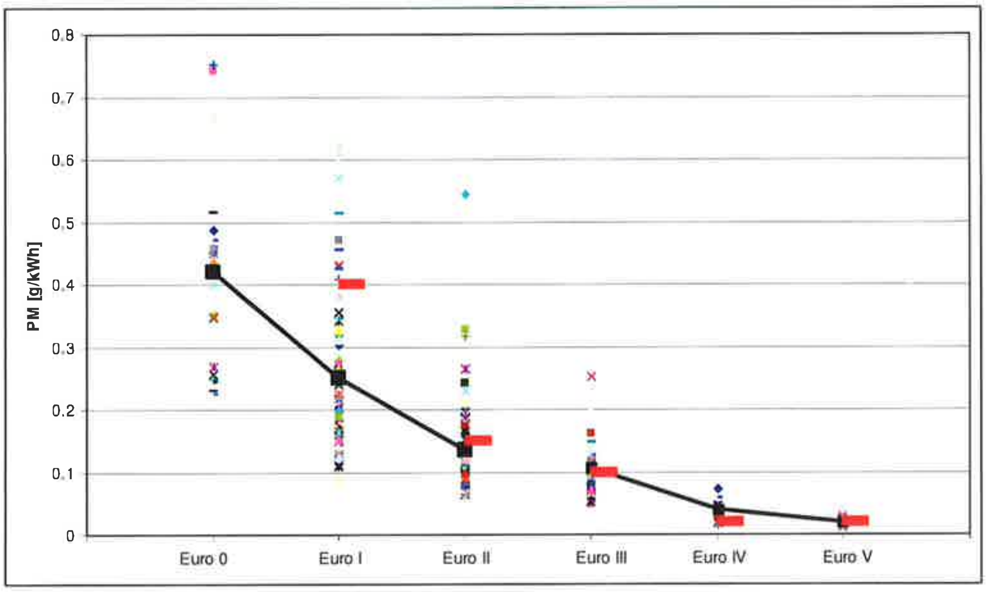
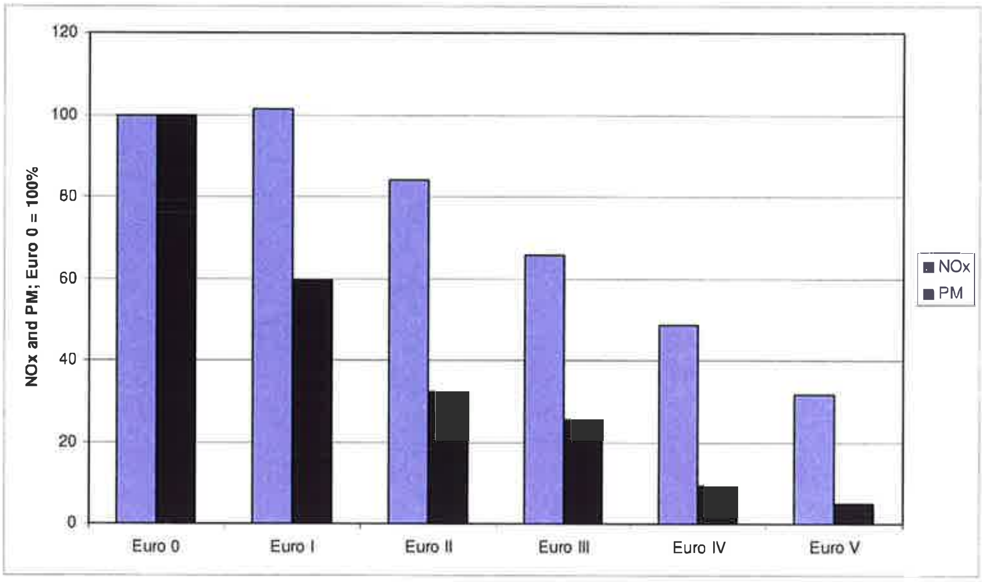
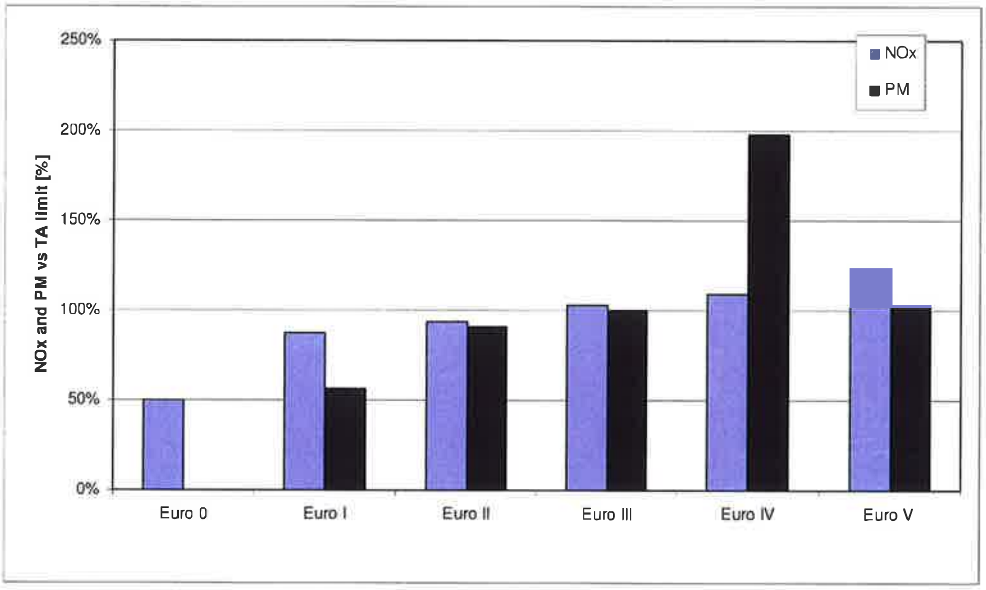


Figure 11; the progress of HD engine emissions of PM and NOx as measured over the ECE R49 test (for Euro 0 to Euro II) and the ESC test (for Euro III tot Euro V) relative to Euro 0. Values have not been corrected with durability factors



When the average results of each legislative category are compared to the TA limits, see the picture below, it can be observed that the stricter the legislation becomes the more the average nears or even passes the limit. For the Euro IV class a remarkable overshoot can be observed. This might be explained by the typical technology dominating engines in that legislative class (EGR or exhaust gas recirculation). The observations are further explained in paragraph 2.1.3.

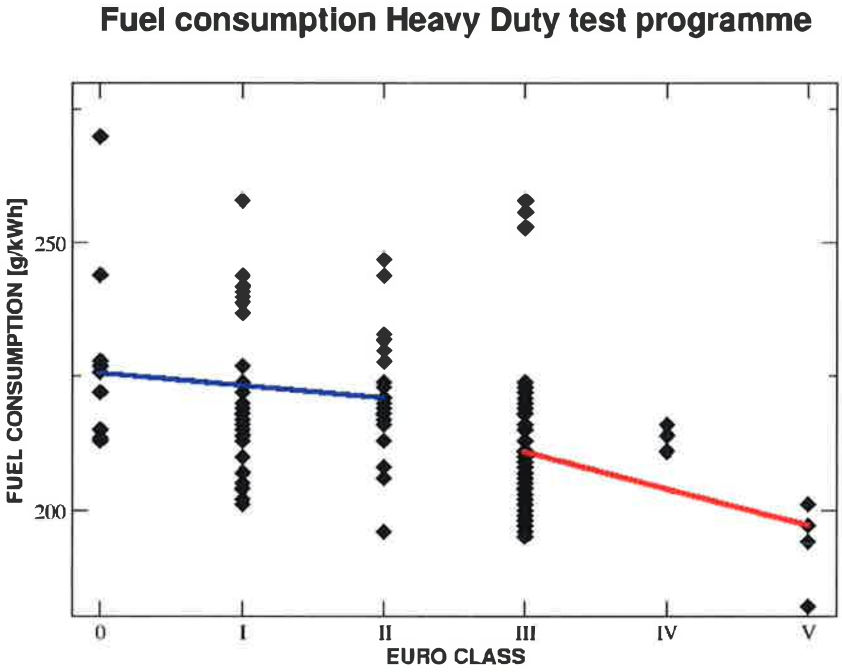
Figure 12; the progress of HD engine emissions of PM and NOx as measured over the ECE R49 test (for Euro 0 to Euro II) and the ESC test (for Euro III tot Euro V) relative to the respective TA limits. Values have not been corrected with durability factors.



The next figure shows the trend for the brake specific fuel consumption going from Euro 0 to Euro V. On average the brake specific fuel consumption (efficiency) has become better over the years. The Euro 0 vehicles are from the early nineties '90-'93.

The scatter is not only from the test variance, but also from the difference in engine performance per engine type. Smaller engines tend to have a somewhat higher brake specific fuel consumption than larger engines. Furthermore, some engines are more tuned towards a low bsfc than others, often at the cost of NOx and with a benefit for PM.

Figure 13; trend of the specific fuel consumption going from Euro 0 to Euro V.



2.1.5 *Results ESC; Special cases*

MA76 Euro IV

The first ESC on the MA76 with PM-kat resulted in a high PM emission of 0,073 g/kWh. This was communicated to the manufacturer. At a second test run three more tests were performed and in discussion with the manufacturer the PM sampling filters were analyzed. A high fraction of sulphates was found on the filters what might indicate that some amount of the sampled PM (0.021, 5.5 and 5.7 g/kWh) could be related to a possible high sulphur content of the fuel as used in the vehicles history. Conclusion from the manufacturer is that much sulphur was stored in the PM-kat at trips with relatively low exhaust gas temperatures (250 to 300 °C) and that a release of particles is forced under the typical test modes were the exhaust gas temperatures rise to 450 °C or more. The sulphur, however, could only explain a small share of the high PM. The rest of the elevated PM emission could, according to the manufacturer, be related to PM release from the PM kat; the conditioning would have been to short or could be related to PM release from the measurements system; at low PM levels contamination of the measurement system could significantly contribute to high PM levels. This last matter has been examined by performing repeated tests on one Euro V engine, see 3.7. Here the repeatability of the same test procedure, but another truck, proved to be around 0,002 to 0,005 g/kWh.

This still does not explain the high PM of the MA76 and therefore the high PM emission is probably related to PM emission from the vehicle itself.

Another vehicle with the same engine type could not be arranged. There were no respondents from the mailing and even calling owners did not lead to finding a suitable vehicle for proceeding with this engine series. Therefore, another engine range from MAN with PM-kat was selected (MA89) to check for issues with the technology. This engine performed well over 3 engines. Only one just exceeded 0,02 g/kWh by a few mg/kWh, the two others were just below the TA limit. On average the MA89 performs 1 mg/kWh below the TA limit.

Table 7; PM results over the ESC of two test sequences

	MA76_1a	MA76_1b1	MA76_1b2	MA76_1b3
ESC PM [g/kWh]	0,073	0,059	0,035	0,036

SC80 Euro IV

Two vehicles were tested. The engines have emission control based on EGR. The first engine was in a general bad condition and had high oil consumption. The second one seemed in better condition. Both engines performed not so well for both NOx and PM. In case of the first engine the high PM emission might be caused by the high oil consumption. For the second engine it remained unclear. On average both engines exceeded TA limits by 36% for NOx and 108% for PM.

A special test was added to these both vehicles to verify the emission behavior at simulated low ambient temperatures. The ambient temperature sensor was disconnected and replaced by a potentiometer to be able to vary the temperature as would have been measured by the sensor. An ESC emission test with 0°C adjusted with the potentiometer (this temperature also indicated on the dash board) lead to a NOx emission of 9.0 g/kWh. The same test was repeated at the second vehicle, here the setting of 0 °C lead to 8.4 g/kWh. Another test at a fixed test point, changing the simulated temperature from 20 to 0 °C showed a rapid increase of the tail pipe NOx concentration as of 7-9 °C. Further examination of the results showed that the measured inlet manifold temperatures were much lower than for the test at the normal simulated temperature of 25 °C. Probably, this lower inlet manifold temperature is caused by the fact that no or less EGR was used at the simulated low temperatures, hence the high NOx emissions. Examination of the test results of both ESC tests also showed a significant decrease of the specific fuel consumption of a few, up to 10% per mode point. A report [Vonk, 2006] with the test results was send to the responsible TAA.

SC86 EuroIV

Another engine series (SC86) that followed up the above described engine series was selected to check for the same problems. Here the NOx concentration and manifold temperature changes as of 0 °C, which is allowed in legislation to protect the EGR system from contamination issues. The NOx emissions at normal test conditions were well below the TA limit. The PM emissions, however, were very high; 137% above the TA limit for both engines on average. Special preconditioning at high load and repeatability tests have been performed, resulting in no clear picture of the cause. Also a regular check on the injectors spray pattern did not lead to a clarification.

At the return trip, of the vehicle to the owner, an emission malfunction was indicated by the MIL. At the road side a Scania service mechanic diagnosed a malfunction of the pneumatic distribution valve of the EGR control. This error is known by the manufacturer. Under warranty, a replacement part was mounted to fix this error.

MB79 Euro V

The first engine tested, exceeded the NOx limit with respectively 26 and 34%. Together with the Dutch DaimlerChrysler importer it was noted that during the tests NOx peaks occurred during the mode points. The ECU shuts the ad blue injection off when a mode point is not stable enough. Without such NOx peaks the test would have been passed. When the second engine was tested such behaviour was not noticed again.
For the first engine also the PM emission exceeded the limit, by about 80%. The second test with the same engine exceeded the PM limit with only 8%. With the second vehicle this same behaviour was observed again. The stability or repeatability of the PM measurement has been examined by performing repeated tests on one Euro V engine, see 3.7. Here the repeatability of the same test procedure, but another truck, proved to be around 0,002 to 0,005 g/kWh. This level of repeatability still does not explain the high PM of the first tests of both vehicles and therefore the high PM emission is probably related to PM emission from the vehicle itself.

MB 82 Euro V

The first vehicle was investigated two times. After the first measurements the truck seemed to have some problems with the emission reduction (SCR) system. The NO_x-emission exceeded the Euro V limit with 249% over the ESC-test. The OEM was contacted and asked for a clarification of the problem. Therefore, the truck was sent back to the owner, the Dutch DaimlerChrysler distributor vested in Nijkerk. After further research by the distributor it appeared that the vehicle had missed an important upgrade session. The reason why this vehicle missed this upgrade was not clear, but after this appearance DaimlerChrysler claims to have started a search and recall action for all vehicles that missed this upgrade. According to the distributor the upgrade amongst others consists of replacing the urea tank. The vehicle was upgraded by the distributor and was sent for control to DaimlerChrysler Stuttgart. TNO received the vehicle for the second time for emission tests and the operator noticed that with the upgrade also other hardware was involved. A part of the exhaust, the urea dosing unit and the urea nozzle were replaced. A second vehicle was tested afterwards and together with the upgraded first vehicle the vehicles on average exceeded the TA limit by only 8%.

2.1.6 Durability

With regard to durability or ageing, for the tested vehicles no clear relation has been found with mileage. Most vehicles tested were driven less than 200.000 km, with exception of one which has 440.000 km on the odometer.

Figure 14; emission of NOx in relation to vehicle mileage for both Euro IV and Euro V.

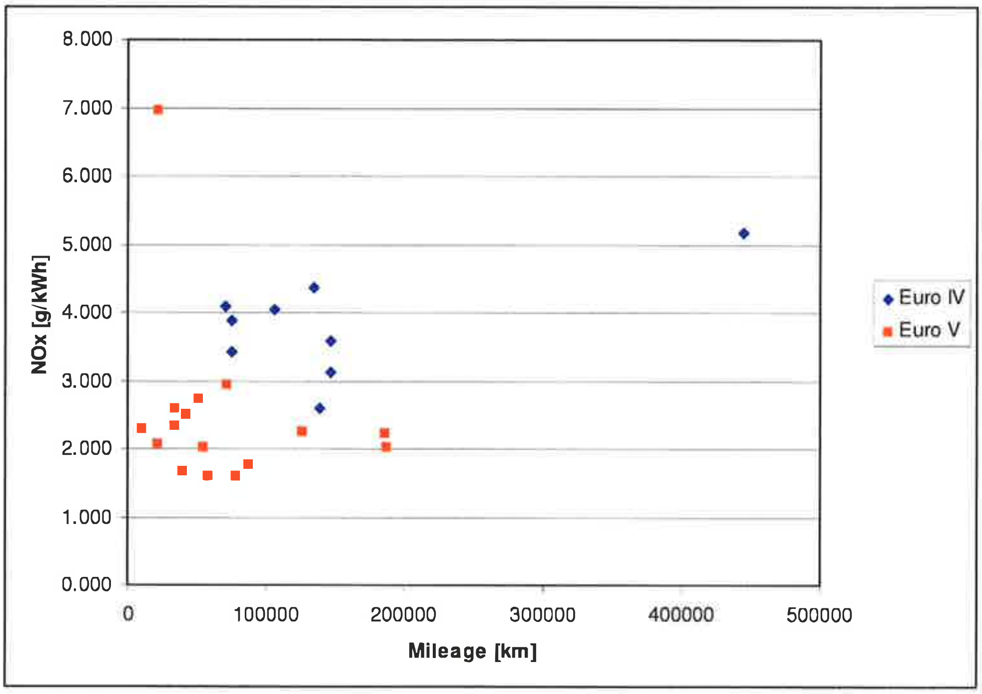
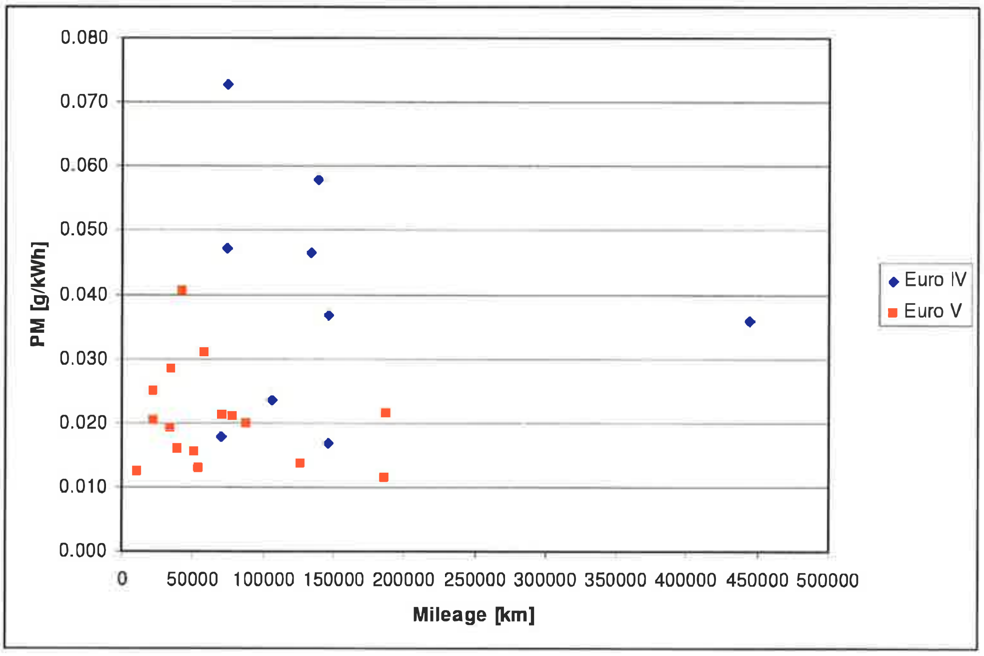


Figure 15; emission of PM in relation to vehicle mileage for both Euro IV and Euro V.



2.2 On road measurements with PEMS

2.2.1 Introduction

To adapt legislation for checking the real world emissions, In-Service Conformity or Off-Cycle emission performance a method is being developed which can measure these emissions under real world circumstances in a vehicle. The method which is currently examined by the EC for integration in EU emission legislation is the PEMS method. PEMS stands for Portable Emission Measurement System. PEMS is already applied in the U.S. In-Use Compliance legislation with the NTE (Not To Exceed) approach. This NTE approach was not found effective for the special situation in the EU.
In the EU a special PEMS working group has been set up, which examines the method for its suitability for integration in EU legislation in a PEMS Pilot Programme. Additionally, the EC looks at covering a broader spectrum of the practical circumstances, so that PEMS can be used in the EU with increased effectiveness.

Truck manufacturers, engine manufacturers, Technical Services, Type Approval Authorities, Member States, equipment manufacturers as well as a group of consultants contribute to the PEMS Pilot Programme. In the programme the test procedure is conducted as laid down in the PEMS Pilot Programme Project Plan [DG ENTR, 2007]. In this plan all test conditions are written down to be able to conduct the testing for the Pilot.

The EU PEMS Pilot Programme has several goals:

- To validate the use of PEMS for in-service conformity;
- To evaluate the PEMS test protocol and its implementation;
- To provide further information on incorporating the PEMS approach in the European type-approval legislation;
- To develop and share 'best practice' approach for the use of PEMS in ISC testing to all relevant stakeholders;
- To benchmark the dialogue between manufacturers and type-approval bodies (reporting format);
- To address open technical issues of the PEMS Project (in particular use of after-treatment systems, cold start and PM measurement).

Because of the developments in the field of EU emission legislation the current PEMS systems have considerably improved over the previous years in the field of exactitude, robustness and user friendliness. The systems seem a relative simple and cost-efficient means to measure emissions under real world conditions in a vehicle. The systems are however not entirely mature. Thereby findings from the practice indicate that working with PEMS systems is not always simple and that the application of these systems in practice sometimes appears more cumbersome than expected. Because all developments of the emission legislation seem to go in the direction of using PEMS for In-Service testing, it is important to gain experience with such systems, testing emissions in a vehicle on the road under real world driving conditions.

Therefore, PEMS has been introduced in the Dutch In-Service Testing programme. The goals are:

- to determine the performance of a PEMS in terms of absolute accuracy
- to gain experience with evaluating and interpreting results obtained with a PEMS
- collecting HD real world emission data and driving data for the purpose of emission modelling
- to gain insight into real world emission behaviour of HD vehicles
- to contribute to the EU Pilot programme for determination of a pass fail method with pass fail criteria
- to determine the robustness of the EU PEMS procedure with regard to detecting malfunctioning of emission control devices of HD vehicles In-Use.
- to collect emission data for use by the TAA

By developing such knowledge VROM and TNO can:

- value PEMS system and its results
- gain insight in real world emission performance of HD vehicles with respect to durability, malfunctions, inspections and maintenance, real world emission levels, other factors of influence
- discuss on national and international level on HD emissions and legislation
- develop and share a vision on how HD emission testing should look like
- deliver real world emission data for national en international emission modelling
- develop real world driving cycles, for use on engine test beds and vehicle test beds

2.2.2 *Vehicle selection*

The vehicle selection is somewhat different from the one used for the ISC part of this programme applying the simulated ESC on the chassis dynamometer. First of all, it is the goal to gain experience with testing itself so that an easy vehicle for installation of PEMS in the first stage of the programme is desirable. Ongoing, more focus has been given to representativity and special vehicles. The baseline for the selection was to choose vehicles with Euro V HD engines installed and to start with rigid trucks and later on to move to tractor trailer combinations and busses.

Table 2.8; vehicles tested with PEMS in the period December 2008-July 2009.

TNO testing Code	Vehicle manufacturer	Vehicle type	Vehicle	Engine type	Power [kW]	Mass [ton] Empty* / load / empty+load	Legislative category	Emission control
VO90	Volvo	FE S	Rigid	D7E320 EC06B	235	9,5 / 3,3 / 12,8	Euro V B2(D)	SCR+AMOC
IV91	Iveco	Stralis	Rigid	F2BE3681C	228	9,8 / 6,55 / 16,4	Euro V B2(D)	SCR
DA92	Daf	CF75	Tractor trailer	PR228S2	231	12,3 / 7,6 / 19,9	Euro V B2(D)	SCR+AMOC
SC93	Scania	R440	Tractor trailer	DC13 10	324	17 / 12 / 29	Euro V B2(G)	2-stage EGR
DA94	Daf	XF105	Tractor trailer	MX300S2	300	15,8 / 13,8 / 29,6	Euro V B2(E)	SCR+AMOC
DA95	Daf	LF45	Rigid	FR118S3	117	5,58 / 1 / 6,58	Euro V EEV C(I)	SCR+AMOC
MB96	Mercedes Benz	Axor	Tractor trailer	OM457 LA V/3	295	15,3 / 13,6 / 28,9	Euro V B2(D)	SCR
SC97	Scania	R420	Tractor trailer	DC 12 15	309	17,8 / 12 / 29,8	Euro V B2(G)	SCR
VD98	VDL	Ambassador	City Bus	Cummins ISBe5 225B	165	9 / 3 / 12	Euro V EEV C(I)	SCR + CRT

* 'empty' is the weighted mass of the whole vehicle, thus including a trailer if applicable

2.2.3 *Test procedure*

The test procedure consists of at least two days of testing on the road, driving the following trips;

- Representative trip; according the PEMS documents [DG ENTR, 2007], [DG JRC, 2007], [DG JRC 2009] for ISC testing a representative trip should be driven over which the emissions shall be evaluated. This trip and its results are also very useful for the development of representative driving cycles and emission factors.
- Standard Reference Test Trip; a predefined standard trip is applied for all vehicles. The trip includes different road types; urban, rural, highway; with all relevant traffic situations. A cold start is included, as well as a coast down to determine the vehicles driving resistances, rolling resistance and drag.

For items of specific interest other tests may be chosen;

- additional cold trip (winter)
- additional load situations (empty, half, full)
- no Adblue, water diluted Adblue, other faults
- effect of auxiliaries.

Figure 16; example of a representative trip

Figure 17; the reference trip starting at the TNO location in Helmond, driving the trip clockwise.

2.2.4 *PEMS; overview results*

2.2.4.1 *Pass-fail results NOx*

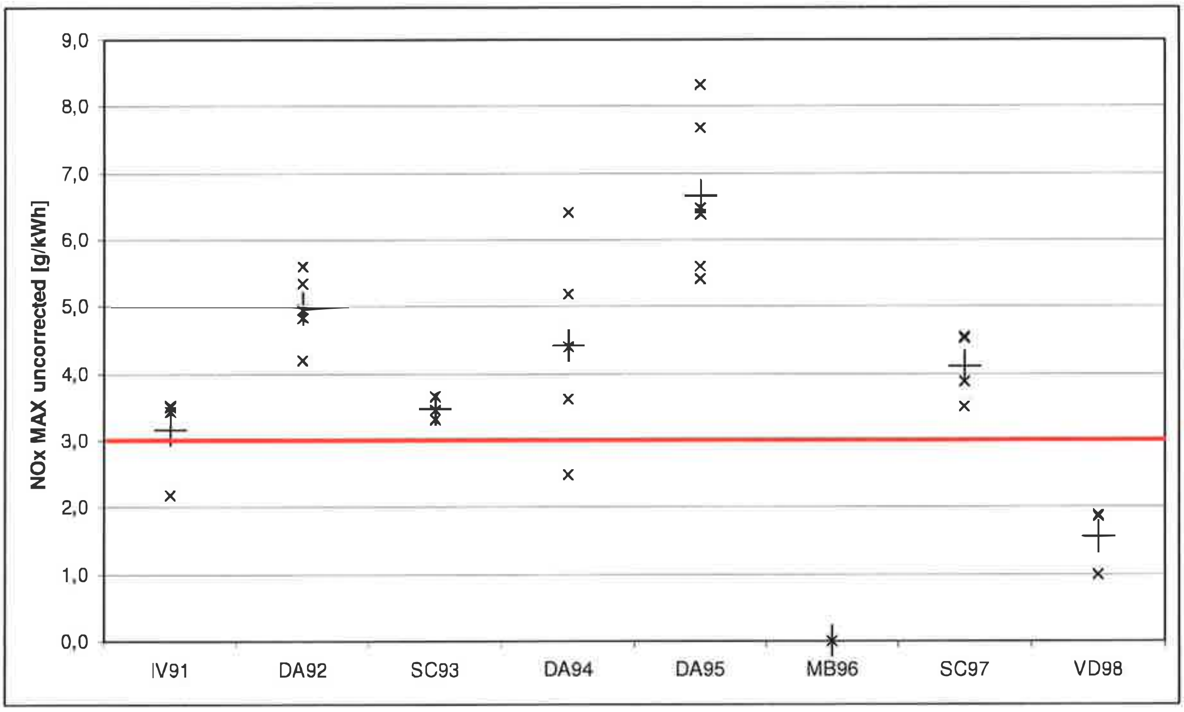
In the EU PEMS work group a pass fail method and pass fail criteria have been developed. The pass fail method for Euro V vehicles is at the moment based on the work based window method [DG JRC, 2009]. The exact method is still under discussion. The method calculates the average specific emission over a window as large as 3 times the work over an ETC test. Windows with an average power below 20% of the rated power or an engine coolant temperature below 70 °C are deleted. Additional criteria are under discussion, like deleting 10th percentile of the windows with the highest values. The vehicles are driven with 50% payload as prescribed in the PEMS technical Guide [DG JRC, 2007].

The graph below gives an overview of the tests driven with 50% payload; both the loaded reference test trip around Helmond as well as the representative trips as driven according the vehicles normal usage. Also the average values of the pass-fail result of all trips are given.

As can be observed from the picture only one vehicle, the city bus (VD98), performs better than the pass-fail criterion currently under discussion, namely 1,5 times the NOx limit over the ETC test, which is 1,5 x 2,0 = 3,0 g/kWh. Two others (IV91 and SC93) are just above the 3,0 g/kWh, but especially the DA95, a light Euro V EEV distribution truck performed very bad compared to the 3,0 g/kWh. The reason is that the SCR catalyst did not get very warm during the representative trips.

Also for some vehicles there is scatter between pas fail results of trips. This means that following the same procedure rather different results can be produced. For DA94 the vehicle could pass if the lowest result was produced. The scatter can be explained mainly from the driving conditions. For the DA94, for example, the lowest pass fail value was produced at a trip starting with highway operation, ending with urban operation. Entering the urban driving conditions from the highway the SCR catalyst was very warm and probably did not get a chance to cool down, thus still efficiently reducing NOx. The higher values are typically produced when the trip was started with urban operation, hence low average engine loads, or when urban operation and/or idling typically lasted long enough to cool down the catalyst to temperatures at which NOx isn't reduced with a high efficiency anymore. Bottom line is that different results can be produced by choosing different trips. This means that the procedure is not very robust.

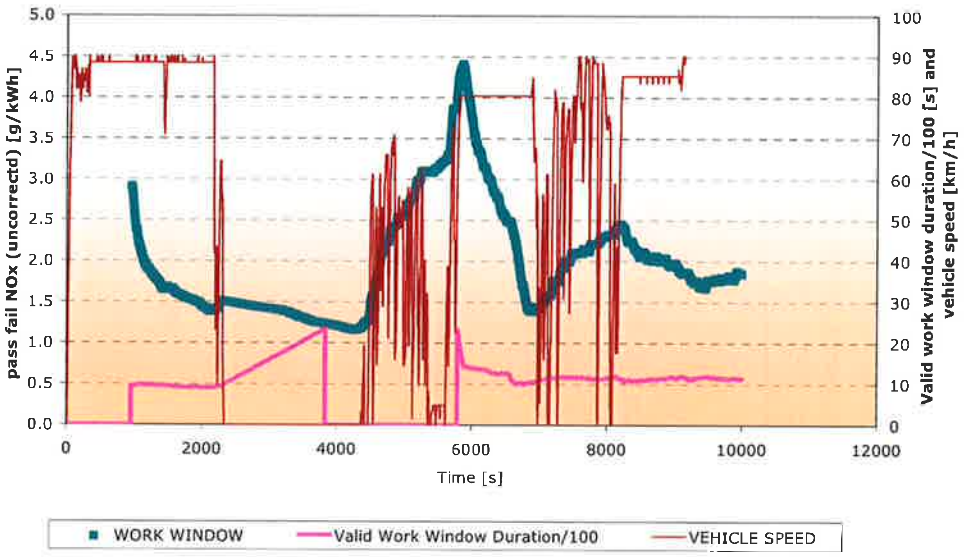
Figure 18; pass-fail results of the uncorrected specific NOx emissions over representative trips and the 50% loaded reference trip; using Emroad v3.8, the work window method, applying a work window of 3 times the ETC work and applying a power threshold of 20%. The pass fail criterion is set at 3,0 g/kWh, which is the limit currently under discussion. The results are uncertain due to the uncertainty of the measured work as determined from the vehicles ECU. For MB96 no ECU data became available, so no emissions could be calculated in g/kWh.



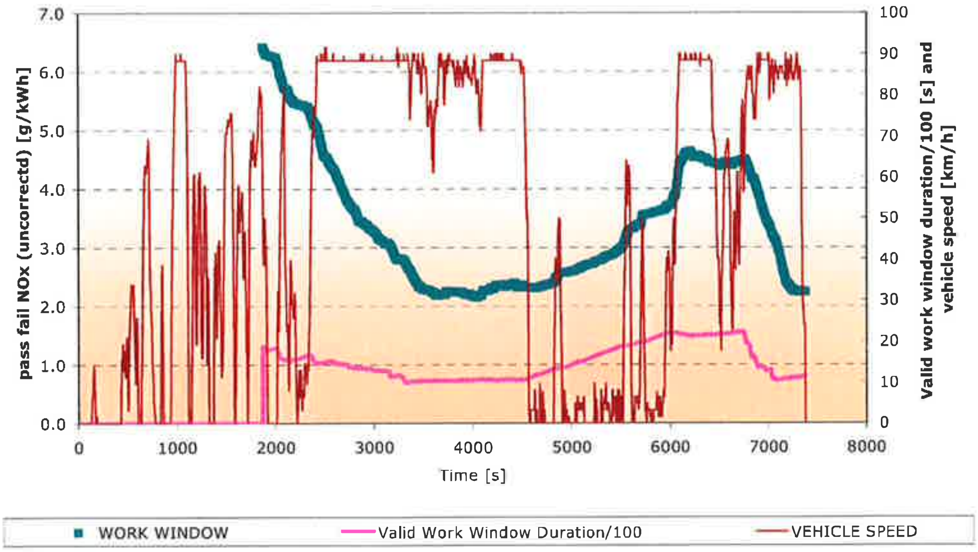
For Euro V engines emission regulation is already into force, while the PEMS procedure is not fully completed. The procedure can therefore never judge an engine as being not in Conformity with its Type Approval as the Type Approval test remains decisive. For this reason it is more or less accepted that the PEMS procedure for Euro V engines aims at conditions resembling the ETC, which generally has warm operating conditions (no cold start) and a relatively high average engine load. If such operating conditions would have been matched on the road probably lower pass-fail NOx values would have been produced.
Nevertheless, this clearly stipulates the problem with the Euro V type approval procedure; the exclusion of a cold start and the lack of sufficient low load operation leads to engines only optimized for ETC alike conditions and even in that case the engines are tuned very closely towards high NOx, saving ad blue on the way.

2.2.5 *Looking into the pass-fail method*

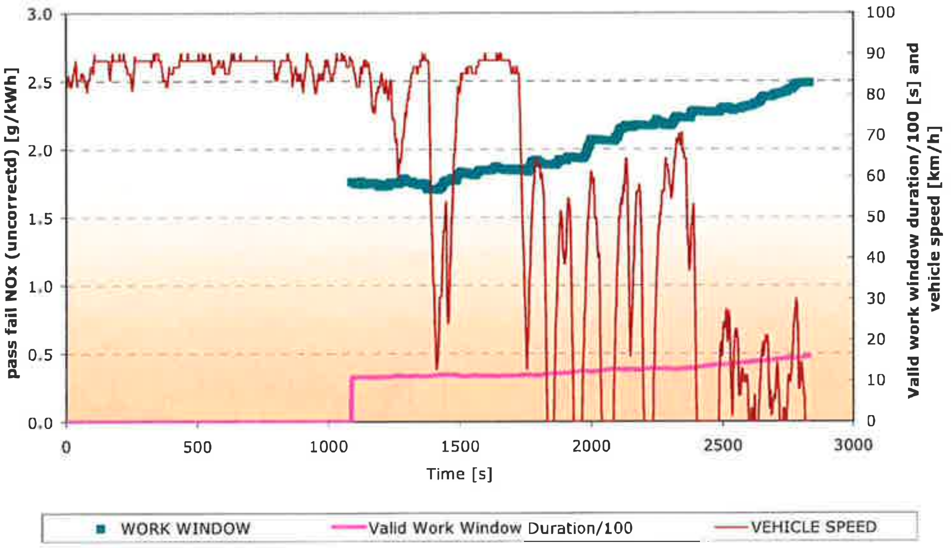
The picture below (DA94) explains the typical behaviour of the procedure; the green dots are the average NOx values over a window as large as 3 times the ETC work. The pink line shows the duration of a valid work window taking the 20% power threshold as criterion for exclusion of windows. Obviously this vehicle performs very well entering the first valid work window from highway conditions starting with a NOx of around 3.0 g/kWh decreasing over highway usage to even 1.5. When the vehicle idles the work window duration starts to increase until at a certain point the 20% power threshold is reached and windows are excluded. Proceeding with urban operation the first valid window already starts at 4 g/kWh and raises to 4,4 which in the end will be the pass fail NOx result for this trip (using no further exclusion criteria like selecting percentiles of the data). Again proceeding with highway operation the values again decrease sharply.



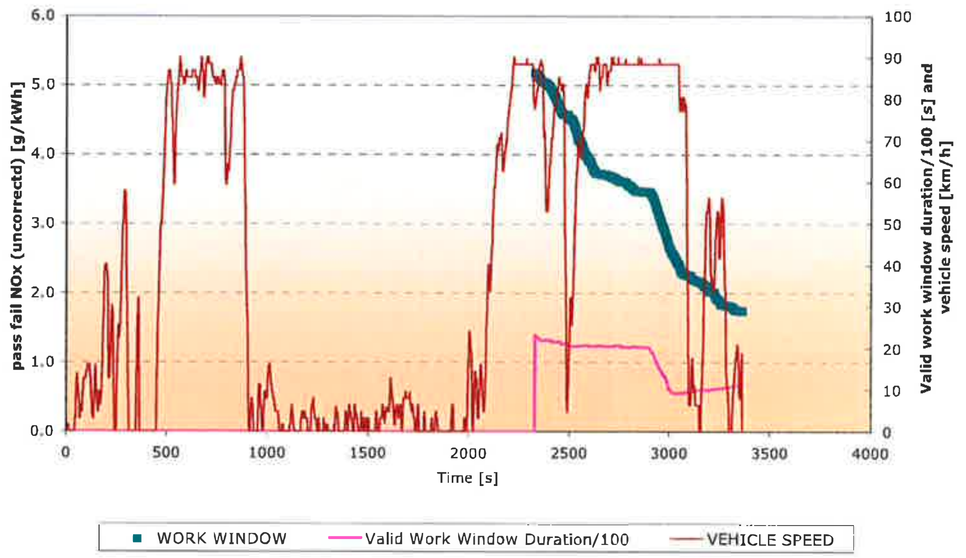
At the next picture the vehicle (DA94) starts with urban operation; the first window with three times the ETC work and an average power higher than 20% starts at 6.4 g/kWh. The high first value is caused by the fact that the engine and catalyst were cold at t=0. At t=990 the coolant temperature reached 70 °C and the first valid window thus occurs at t=2481 (990 + window size) and then the NOx is 4.6 g/kWh.



Here is a picture of DA94 starting with highway operation; the result is well below the pass fail criterion of 3.0 g/kWh.

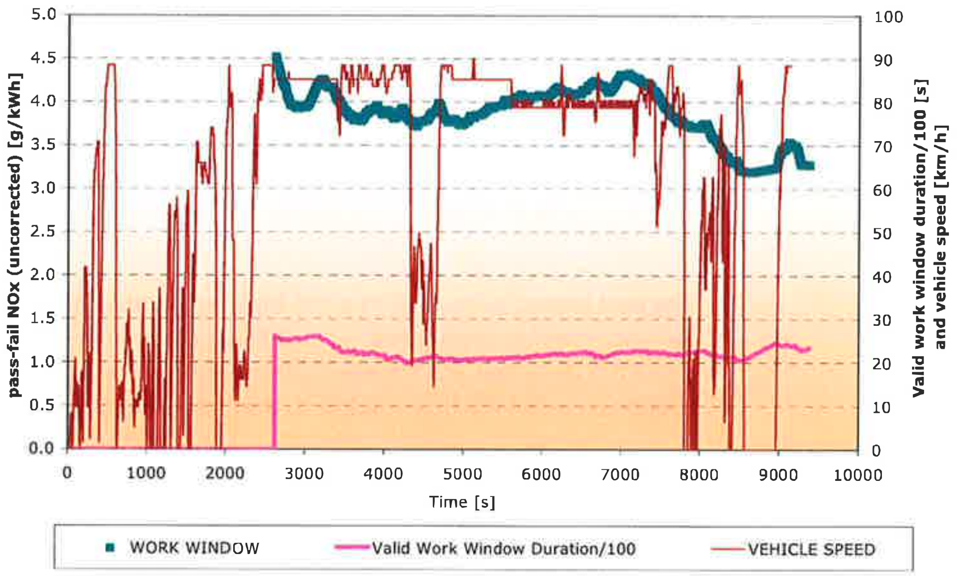


The next picture shows DA94 at the highway; starting from a depot unloading goods the vehicle enters the highway at t =400+ and before t=1000 enters a traffic jam at A27 Utrecht-Vianen and A2 Vianen – Culemborg. The traffic jam with low speed, low load operation caused the first window to start late in the trip and above 5.0 g/kWh.

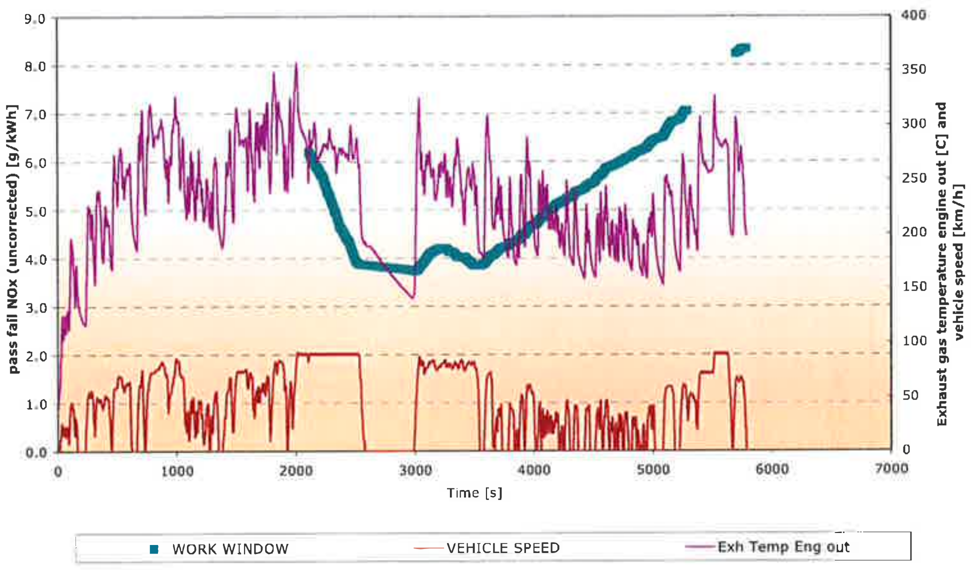


2.2.6 *PEMS; remarkable cases*

The next picture of SC97 shows that the vehicle produces reasonably stable results of around 3.5 to 4.5 g/kWh at the highway. The exhaust gas temperature appeared to be around 300 °C on the highway and so the SCR should work optimal. This vehicle produces bad results of more than twice the ETC limit even though the conditions are there to have the SCR functioning really well. The same engine type (DC12 15) was tested before on the chassis dynamometer over an ESC. There this engine also produced high NOx emissions, though not as high as tested here with PEMS. Over the ESC two engines of this type were tested; the results were 2,94 g/kWh for the first engine and 2,25 g/kWh for the second engine.



The DA95, a Euro V EEV light distribution truck has a remarkable high pass-fail NOx of 8.3 g/kWh over the trip presented in the next figure. The lowest values are obtained coming from the highway (warm SCR kat) and entering the highway again. But still the results are only just less than 4.0 g/kWh at the minimum. After the second highway part NOx starts increasing to a level of 8.3 g/kWh. The small break at the end is due to the windows average power dropping below the 20% threshold. As can be seen from the measured engine out exhaust gas temperature the level is very critical for SCR operation. This has probably caused the high NOx results.



2.2.7 *PEMS; special cases*

Additionally, some special cases have been tested; the overall results are presented in the picture below. Three vehicles were tested under different conditions to see if the Emroad procedure is sensitive to failures or changes which are made on purpose in two cases to see if te OBD system functions properly to emission related malfunctions.

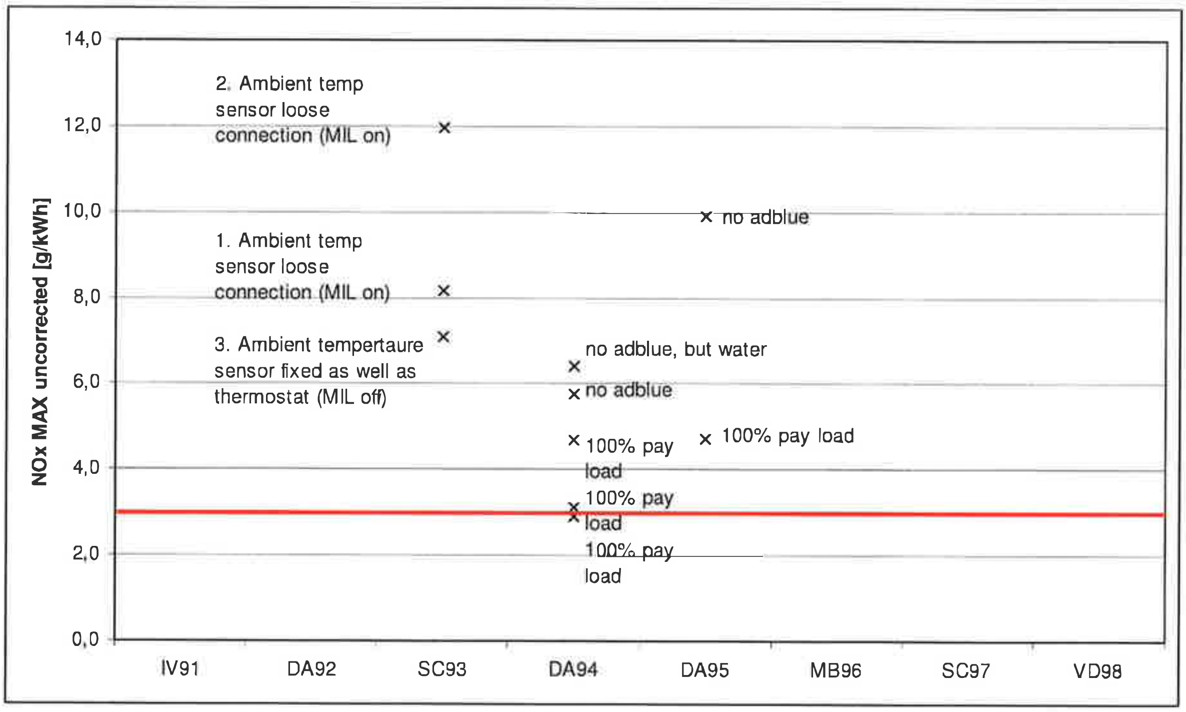
- DA94 and DA95 were driven with pay loads of 100% instead of 50%
- DA94 and DA95 were driven trips with no ad blue in the reagent tank
- DA94 was driven with water in the reagent tank
- SC93 was driven with the ambient temperature sensor connection broken

For SC93 the high NOx emission is probably caused by the fact that the ECU does not get a realistic ambient temperature. Due to the broken connection the resistance of the NTC sensor is infinite and thus the ambient temperature could potentially be very low. As a result the two-stage EGR was switched off; hence the NOx emission rose to very high values. The OBD system responded and switched the dashboard light on, indicating an emission error. The connection was fixed after (2) as shown in the picture and the indication light was off. Test 3 still resulted in elevated NOx emissions at the beginning of the trip, but gradually decreased during the trip to levels detected earlier, before the problem occurred.
According legislation an EGR may be switched off at low ambient temperatures. A manufacturer may requests authorization for this strategy at type Approval.

For DA94 and DA95 the elevated NOx emissions are obviously caused by the fact that no reagent is available for reduction of NOx in the SCR catalyst. For DA94 in both situations (without ad blue and with water in the urea tank) the OBD system responded;

- without ad blue in the tank the engine power was immediately reduced, after filling up the system the engine power was immediately at a normal level.
- with water in the urea tank after approximately one hour of driving the dash board indicator light went on. After filling up with ad blue the indicator light went off after one hour of driving.

Figure 19; pass-fail results of the uncorrected specific NOx emissions over representative trips with errors or some deflections (given in the picture) from the standard procedure; using Emroad v3.8, the work window method, applying a work window of 3 times the ETC work and applying a power threshold of 20%. The pass fail criterion is set at 3,0 g/kWh, which is the limit currently under discussion. The results are uncertain due to the uncertainty of the measured work as determined from the vehicles ECU.



3 Additional investigation and tests

3.1 Emission related malfunctions

From the vehicles tested the malfunctions with a relation to emission performance were recorded. The major goal is to scan for problems with the technology used to reduce emissions, but also for other technical aspects which might influence emission behavior. The current legislation foresees in procedures to confirm the functionality of the emission control devices during the useful life of an engine installed in a vehicle under normal conditions of use. (2005/78/EC). But such a procedure only aims at vehicles which had proper maintenance and are used under normal conditions.

The Dutch programme also aims at revealing possible problems not applying the official procedures to gain insight in real problems occurring in practice. Therefore during the programme all errors and malfunctions were recorded. In the past mainly pre and post maintenance tests were performed to check for the state of maintenance and the effect on emissions.
Nowadays, engines are electronically controlled and often have exhaust gas after treatment systems and no adjustments can be made anymore to these systems. This means that it became interesting to investigate the functionality of these new systems with respect to emission behaviour.

As of Euro V HD vehicles should be equipped with an On Board Diagnosis system to detect and signal emission related malfunctions. During the programme some PEMS tests were performed to see if the signalling function of the OBD is working properly, see also 2.2.7.

Below an overview is given of all problems found.

TNO Test ID	Vehicle/engine	Problem	effect on emissions	Remarks
SC80_1	Scania DT1211	high oil consumption	possibly caused the high PM of this engine	generally truck was in a bad condition
MB82_1a	MB OM457 LA/V3	urea dosage clogged	very high NOx	recall of the trucks; received upgrade of hard and software
VO84_3		(code) Fault injector 1; vibration and power loss	not checked, vehicle did not run well on dyno (vibrations)	replaced injector
SC86_2	Scania DT1212	EGR pneumatic distribution valve not working	No EGR control; effects on NOx expected	No emissions tested; problem occurred after the tests; part replaced under warranty
SC93	Scania DC1215	ambient temperature sensor connection loose	Very high NOx	MIL on

3.2 Emission factors

The annual delivery of the emission factors for the SRMI and SRMII air quality calculations is a process which is started in the autumn of the year before. PBL determines the expected development of shares of the different vehicle categories on the basis of the outcome of Prinsjesdag. TNO then determines the average emissions of the main categories; light vehicles, medium vehicles, heavy vehicles and busses for future years, up to 15 years in advance. As PBL processes the newest economic insights in the shares and volumes of traffic, TNO processes the newest technological insights and measurement results from the Dutch In-Service Testing Programme, other relevant programmes and international research on emission factors. However, the data of the In Service Testing Programmes forms the basis.

In the course of the years the delivery of emission factors has been extended. Besides the standard emission factors for SRMI for some year's emission factors have been provided for special traffic situations, like traffic-jam, several speed limits and maintaining regimes on the motorway, which forms now input for the SRMII.

In 2008, emission factors have been established for the calculation tool for clean buses.

3.3 Other programmes

From within the in-service testing programme contributions have been done to other programmes. Most were programmes reported separately.

- Heavy Duty retrofit DPF programme
- Heavy Duty Bio fuel testing
- Light Duty Vehicle (vans) with a retrofit DPF
- Algea X

3.4 NO_2

The exhaust gas component NO_2 is the most noxious of NOx (consisting of both NO and NO_2). Therefore, ambient air quality regulation in the EU has focused on NO_2 and posed limits for the yearly average ambient air concentrations and for hourly concentrations.

For NO_2 emissions from the source, from light and heavy duty vehicles, in EU legislation no limits have been set for NO_2 but for NOx instead. This mismatch between requirements for local air quality and implementation at the level of the vehicle fleet has lead to the remarkable trend where over the years the ambient NOx concentration gradually decreased whereas the ambient NO_2 concentration sustained.

To supply emission models with the right information regarding NO_2 and to monitor the effect of new technology on the NO_2 emissions the testing programme, which generally only deals with NOx, was extended with the measurement of NO_2.

To correctly measure the instantaneous NO_2 emission attention should be paid to the experimental set up. The measurement should be;

- fast to prevent a shift in chemical equilibrium towards NO_2 (no bag measurement)
- raw to prevent dilution with other substances that convert NO into NO_2 (CO, O_3)
- simultaneous and aligned for NOx and NO to have a reliable online calculation of NO_2
- conditioned with heated sampling to prevent condensation of moist exhaust gas and the resulting loss of extremely soluble NO_2 in the condensed water in the sample line (forming NO and nitric acid).

Special instrumentation was added to the general laboratory test set up to measure the NO_2 concentration over the ESC test cycles mode points. A heated dual chamber chemo luminescence analyzer (Eco physics CLD700-ht) was used to analyze the exhaust gas for the raw NO_2 concentration. A heated sample line was used to prevent condensation of moist exhaust gas.

Below pictures are given with the NO_2 fractions over the ESC test mode points and the complete ESC, shown per vehicle separately. The table shows averages for legislative categories, but also for technology classes (SCR, SCR+AMOC, EGR..).
Remarkable are the high NO_2 fractions for the Euro IV engines with a PM-kat. These high fractions can be explained by the way this particle filter works; NO_2 is produced by an oxidation catalyst integrated in the system. The additional NO_2 helps to regenerate the soot at low filter temperatures as of 250 ºC. The NO_2 is produced as surplus, not all NO_2 reacts with soot, and so NOx with a relatively high fraction of NO_2 leaves the tail pipe. It is known that the fraction of NO_2 produced by an oxidation catalyst is dependent on the amount of platinum, the space velocity, the load of soot and the temperature of the catalyst. Furthermore, the load of the engine itself contributes to changes in NO_2 formation; at low loads and low combustion temperatures a higher fraction of engine out NO_2 is produced than at high loads and high combustion temperatures. All these effects together result in the given NO_2 fractions. For example at low engine load, typically at idle, A25, B25 and C25 high fractions of NO_2 can be observed as the engine out NO_2 fraction is already high and additionally, at low exhaust gas flows, there is enough time in the hot catalyst to convert NO to NO_2.

Also remarkable are the high NO_2 fractions for the Euro V engines with an SCR and an AMOC (Ammonia Oxidation Catalyst). While for engines only with SCR the NO_2 fractions are very low, it can be seen that adding an AMOC probably results in higher fractions of NO_2. Ammonia is thus reduced at the cost of an increase of direct NO_2. This phenomenon can again be explained by the oxidizing function of the AMOC; an AMOC is a small oxidation catalyst.

Figure 20; NO_2 percentage in the NOx emission over the ESC test mode points and as weighted over the complete ESC for the tested **Euro IV** vehicles.

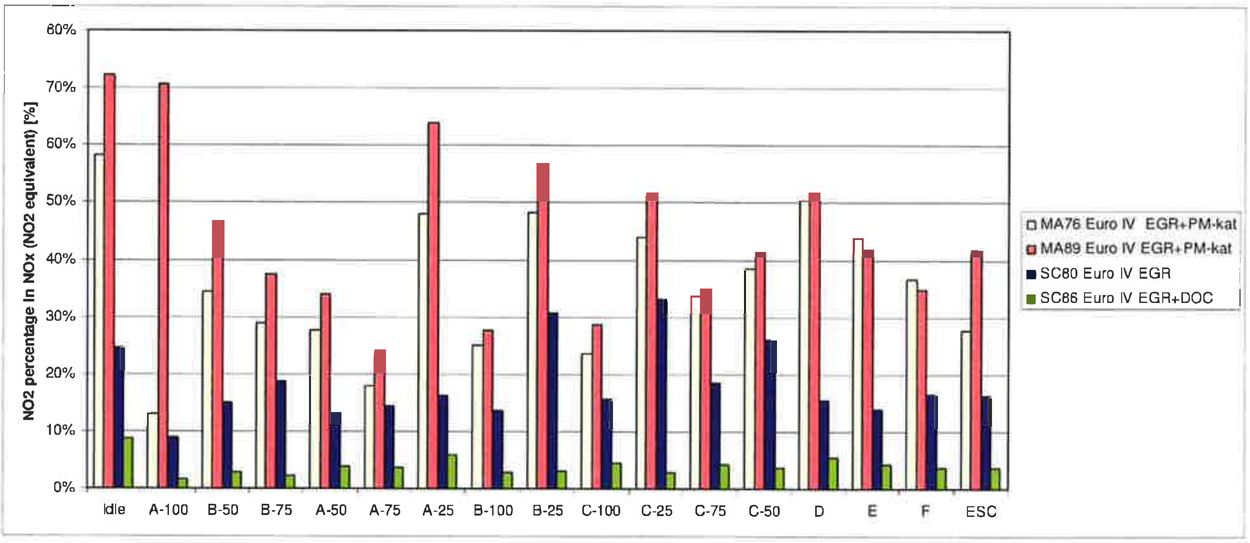


Figure 21; NO_2 percentage in the NOx emission over the ESC test mode points and as weighted over the complete ESC for the tested **Euro V** vehicles.

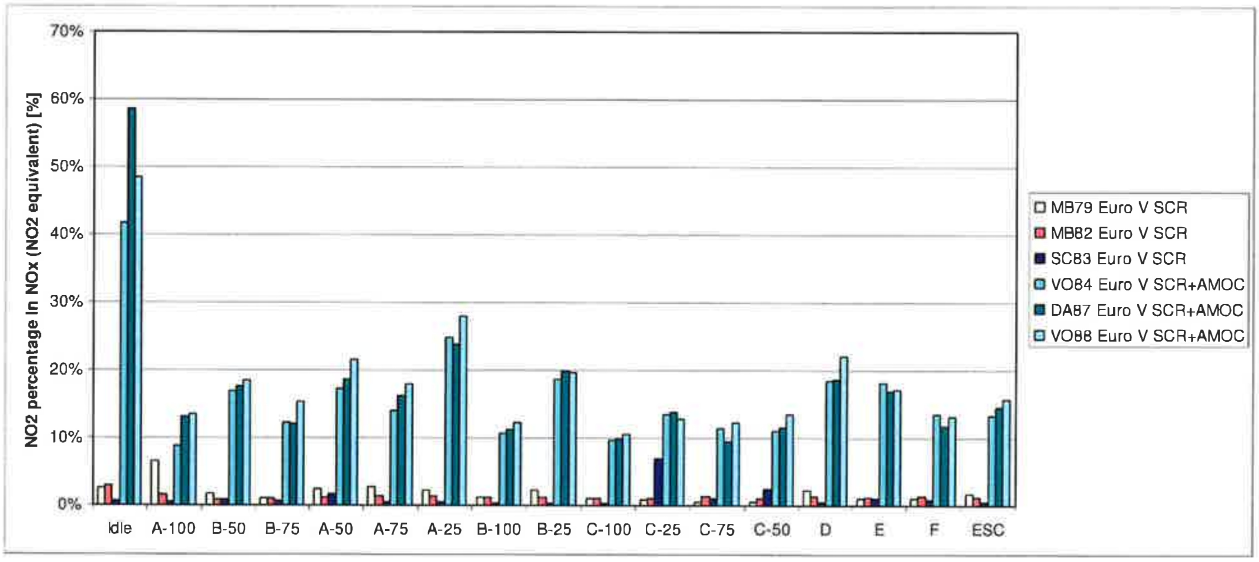
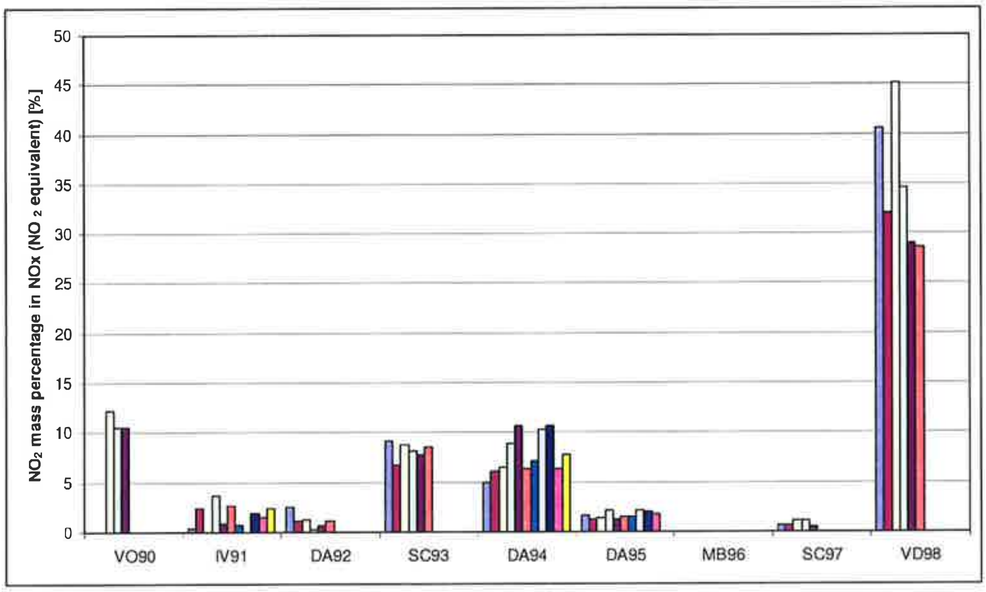


Table 9; NO_2 fractions averaged per legislative category and per technology.

		Average NO_2 percentage in NOx [%]
Euro IV	All Euro IV	24%
	EGR+PM-kat	35%
	EGR	12%
Euro V	All Euro V	8%
	SCR	1%
	SCR+AMOC	15%

Also during the PEMS tests NO_2 has been measured. The measurement principle is somewhat different; in the PEMS the NOx analyzer is based on the working principle with Non Dispersive Ultra Violet (NDUV). In the laboratory this was chemoluminescense. Although, the principles are different, no big deviations due to these principles can be expected.
For these results the VD98 clearly has the highest NO_2 fraction. This is due to the mounted CRT (Continuous Regenerating Trap). The CRT is mounted to obtain the lower EEV limit over the ETC test. This type of particle filter regenerates particles by using an excess amount of NO_2. This NO_2 is produced by an integrated oxidation catalyst. The issue with the elevated NO_2 fraction of this vehicle and problems in the city of Utrecht with local air quality has been extensively reported in [Vermeulen 2009].
The previously observed differences between vehicles with and without ammonia oxidation catalyst (AMOC) (or NH_3-slipcat) can not be observed in the PEMS results. DA92, DA94, DA95 and VO90 have an AMOC. But for DA92 and DA95 no high NO_2 values have been observed. The reason could not be found, but a possible cause could be that the catalyst was not very active due to; a low platinum content, a low operating temperature of the catalyst or even due to catalyst poisoning or deactivation.
The SC93 has no catalyst but 2-stage EGR to control the NOx emission. From EGR engines it is expected that they produce a significant NO_2 fraction, see also the Euro IV EGR engine SC80.

Figure 22; NO_2 percentage in the NOx emission over the PEMS tests.



3.5 NH_3

As of Euro V a large share of HD vehicles is equipped with SCR systems to reduce the tail pipe NOx emission. Such systems operate a catalyst where ammonia, from urea dosage, reacts with NOx to harmless components.
An exact dosage of urea is critical for a good conversion of NOx in combination with a low slip of ammonia. This dosage changes in time due to the transient operating conditions of the engine and the saturation of the catalyst. Hence, a risk exists that some ammonia slips through the catalyst and causes an unpleasant smell of ammonia near the vehicle.

In Euro V legislation a provision has been made with the goal to achieve a low tail pipe ammonia emission. During Type Approval for Euro V it has to be demonstrated that over a test cycle the average ammonia emission does not exceed a maximum of 25 ppm (2005/55/EC, Annex 6.5.1.7.).

Special instrumentation was added to the general laboratory test set up to measure the ammonia emission over the ESC test cycles mode points. An in-situ laser gas analyzer (Siemens LDS6) was used to analyze the exhaust gas for the NH_3 concentration.

The next graph shows the NH_3 concentrations over the ESC mode points of all vehicles with SCR.

Three vehicles were equipped with just a plain SCR system; three others also had an Ammonia Oxidation Catalyst (AMOC) mounted down stream of the SCR, mainly with the goal to oxidize NH_3 in the case of NH_3 slip. Two vehicles with a somewhat higher NH_3 emission were not equipped with an AMOC. Generally, the ammonia emission was very low and well below the allowed average of 25 ppm, see also Table 10.

Figure 23; tail pipe ammonia concentrations over the ESC mode points and the 3 NOx control points (mystery points) of the SCR equipped vehicles.

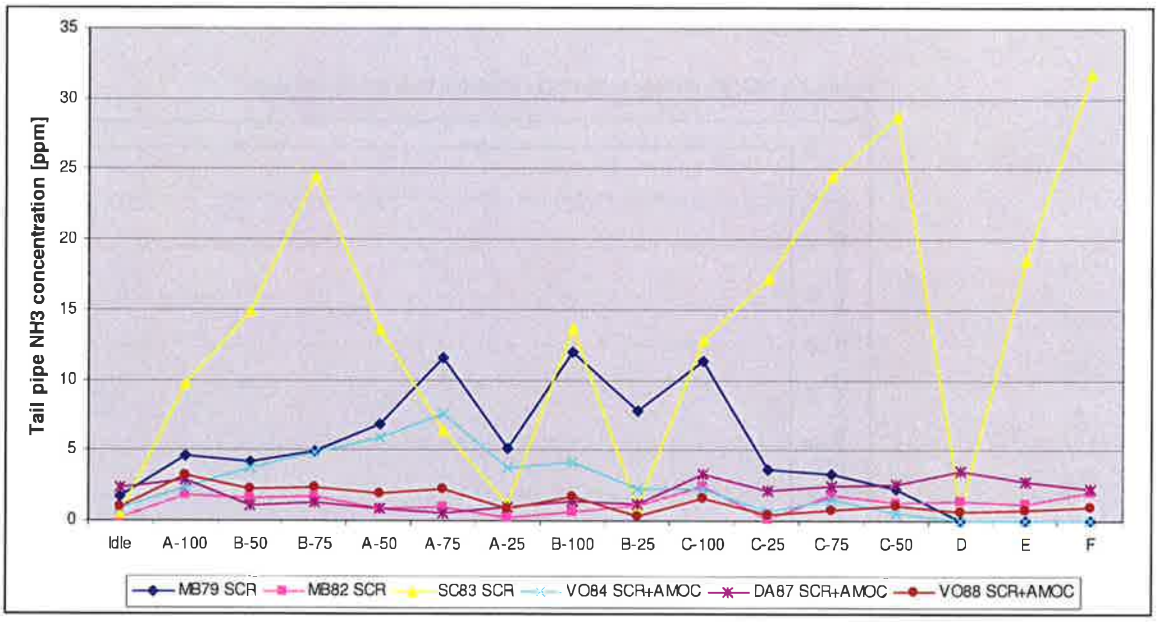


Table 10; average NH_3 concentrations over the ESC tests of the SCR equipped vehicles.

TNO vehicle code	Aftertreatment*	NH_3 concentration
		[ppm]
MB79	SCR	6,1
MB82	SCR	1,1
SC83	SCR	13,0
VO84	SCR+AMOC	3,1
DA87	SCR+AMOC	1,8
VO88	SCR+AMOC	1,5

*SCR; Selective Catalytic Reduction, AMOC; Ammonia Oxidation Catalyst

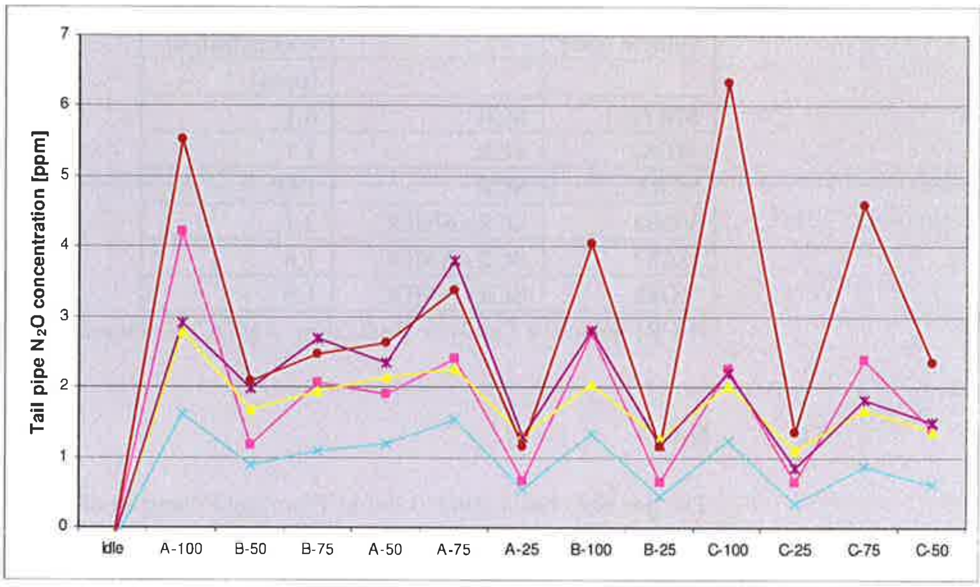
3.6 N_2O

The gas N_2O has a GWP (Global Warming Potential) of around 300, which means it contributes about 300 times more to Global Warming than CO_2. Some catalysts, like the three-way catalyst, are known to produce N_2O under certain operating circumstances. At the time the N_2O problem from these catalysts was investigated it was pointed out that future technology to reduce NOx emissions, like SCR catalysts, could also potentially produce N_2O. A potential effect could never be examined until such technology actually entered the market. The programme as subject in this report was aimed at Euro V vehicles equipped with SCR catalysts and as such this programme became interesting to quickly monitor the level of N_2O emission.

In the graph below the results of the SCR equipped vehicles are shown, per mode point of the ESC. The graph shows concentrations of N_2O, instead of specific emissions in g/kWh. The concentrations shown below are only just measurable. Concentrations in the range of 1-3 ppm mean a mass emission in the range of about 10-20 mg/kWh for typical HD operation. With a GWP of 300 the CO_2 equivalent emission is about 0,5 to 1% of the engines CO_2 emission.

Not included in these measurements is the N_2O emission during warm-up of the catalyst. For N_2O formation in TWC catalysts this warm-up window is the most critical as here the most N_2O is produced and emitted.

Figure 24; tail pipe N_2O concentrations of five SCR equipped Euro V engines over the ESC mode points. These levels of N2O concentration result in a specific emission of about 10-20 mg/kWh. With a GWP of 300 the CO_2 equivalent emission is 0,5-1 % of the actual CO_2 emission of the engine.



3.7 PM Measurement

In the current programme for In-Service Testing of HD engines sometimes large variations of the filter based PM emissions were measured. For Euro III vehicles tested in the 2001-2005 programme these variations were noted as well and were attributed to exhaust contamination. At the testing programme of one engine type with a PM-kat a high PM emission was noted. This was partially due to the history of the vehicle where a high sulphur amount on the test filters would indicate operation on higher concentration sulphur diesel fuel. But, according to the manufacturer, another share of the relative high measured PM emissions would be caused by exhaust contamination. The particulate mass collected during an emission test on the PM filter consisted of particles directly emitted by the engine and additional particles which were released from the exhaust system. This additional particle release from the exhaust system would be caused by the relative high exhaust temperatures which occur during an emission test in a laboratory.

Vehicles equipped with Euro IV and V engines have been selected for the current In-Service Testing programme (2006-2009). These engines have a significant lower level of PM-mass emission (about 5 times) compared to the Euro III vehicles. This means that exhaust contamination may be less and therefore variations caused by exhaust contamination may be decreased. On the other hand, because of the very low emission levels of Euro IV and V engines, the relative accuracy of the measurement itself may decrease and the relative measurement variation may increase.

To be able to judge the PM results from individual engines and to be able to compare the results with the applicable exhaust gas emission limits it is important to have a clear picture of measurement variations and its causes. Therefore, a small test programme was set up to determine the accuracy and variability of the filter based PM measurement for Euro IV and Euro V HD engines and to determine the factors that influence these parameters.

3.7.1 *Test programme*

A total of 11 tests have been performed. First of all, five standard ESC tests were executed to show the variation over this type of tests. Then an additional series of blancs sampled from the tunnel should show variation of the tunnel background and the variation of the measurement itself without influence of the vehicle (weighing, handling, conditioning). During all tests, simultaneous measurements were performed with the Cussons partial flow dilution tunnel and the NOVA partial flow dilution tunnel. The Cussons dilution tunnel has been used during the In-Service Testing programme.

Table 11; test sequence.

#	Test
1	ESC 01
2	Blanco 01
3	Blanco 02
4	ESC 02
5	ESC 03
6	ESC 04
7	Blanco 03
8	Blanco 04
9	ESC 05
16	Blanco 05
17	Blanco 06

Table 3; vehicle specifications

Specification	**Description**
Brand	DAF
Type	XF105
License number	BS-TF-77
Engine code	MX300S2
Emission class	EURO V
Aftertreatment system	SCR
Power [kW]	300
Mileage [km]	87.368

3.7.2 *Results*

The table below shows the results of the 5 consecutive ESC tests. The repeatability of the tests is calculated by means of a Student's t-distribution instead of a normal distribution as from only 5 tests the real standard deviation of a PM mass emission test is not known. A confidence level of 95% was used. Included in the overall variation of these tests is the variation (stability) of the vehicle, the measurements system and the procedure, including possible effects of exhaust contamination.

For the regularly used Cussons tunnel the relative repeatability is about 14%. For the Nova tunnel the repeatability is worse and is 35%.
The average values, calculated over the 5 measurements are approximately the same for both tunnels. Looking at individual measurements differences can become as large as 37%. These large differences seem to be caused by the relative bad stability of the Nova system, see ESC 03 and 05 where the Nova shows a rather high value for ESC 03 and a rather low value for ESC 05.

Table 12; results of the PM mass emission of the 5 repeated ESC tests, measured with both the Cussons and the Nova partial flow dilution tunnels (the Euro V limit is 0,02 g/kWh).

PM	Cussons* [g/kWh]	NOVA [g/kWh]	Cussons/Nova
ESC 01	0,013	0,014	92%
ESC 02	0,011	0,013	85%
ESC 03	0,012	0,017	72%
ESC 04	0,014	0,012	118%
ESC 05	0,012	0,009	137%
AVG 5xESC	0,013	0,013	96%
STDEV	0,00112	0,00292	
r [g/kWh] Spread studentT, 95%, 2-tail	0,00175	0,00456	
R [%] Spread studentT, 95%, 2-tail	14%	35%	

**regular dilution tunnel used for In-Service HD PM emission testing*

To determine the variation of the weighing procedure and the tunnel background concentration a series of blancs was measured from both partial dilution tunnels Cussons and Nova. For both tunnels the blancs vary a lot on a relative basis. The measured concentrations are very low, however.

The variation from the filter mass of the blanc measurements is 0,012 mg for the Cussons. This is about 20% from the total mass of PM collected on a filter during an ESC (0,06 mg), due to partial flow. This means that variation from weighing and background together can already cause variations of 20% in the PM emission. From the repeatability tests shown before the variation of testing with the Cussons is in the order of 15%.

It can be concluded that the mass collected on a filter of a Euro V engine over an ESC test measuring PM with a partial flow dilution tunnel is very low and can show relative large variations from test to test in the order of 15 to 20%.

Table 13; results of the PM mass back ground emission of the 6 blanco tests, measured with both the Cussons and the Nova partial flow dilution tunnels.

PM blancs	Cussons* [mg]	NOVA [mg]
Blanc1	0,023	0,028
Blanc2	0,024	0,030
Blanc3	0,036	0,046
Blanc4	0,031	0,029
Blanc5	0,013	0,073
Blanc6	0,015	0,033
AVG 6xblanc	0,024	0,040
STDEV	0,0089	0,0175
r [mg] Spread studentT, 95%, 2-tail	0,012	0,023
R [%] Spread studentT, 95%, 2-tail	49%	57%

**regular dilution tunnel used for In-Service HD PM emission testing*

3.7.3 *Discussion*

The repeatability of the PM mass measurement over the ESC is about ±15 to 20%.
The test to test variation stems from the vehicle, the instruments and the procedure. The rather high relative variation is caused by the fact that only few PM mass is collected on the filter in a partial flow dilution system.
Small variations during the filter handling procedure (transport, handling, weighing) or from the tunnel background can already add significant variation of the measured PM mass. The amount of these variations was of the same order as the overall repeatability found over 5 consecutive ESC's, which means that the vehicle used for the tests probably has very little variation.

In general the reproducibility of a measurement is typically larger than the repeatability. This means that the uncertainty of a result is even larger than the ±15-20% found within one laboratory. From general emission laboratory experience with PM measurements it is estimated that the reproducibility lies around ±30 to 40%.

It is recommended to take this uncertainty into account when judging the results from individual HD vehicles measured during the current programme; for individual Euro IV and V vehicles and a single test, only results of 40% above the limit can be regarded as 'significant above the limit'. A repetition of tests decreases this uncertainty range.

The currently running EU PMP (Particulate Measurement Programme), [PMP, 2009] is aimed at improving the accuracy of the filter based PM measurement.

3.8 Non-road: In-land waterway vessels

Two inland waterway vessels have been retrofitted and six more vessels will be retrofitted with combined particulate traps and SCR systems from different exhaust gas after treatment suppliers. The SCR-systems are subsidized by the Dutch Ministry of VROM if they meet the requirements as laid down in the VERS subsidy scheme. The particulate traps are subsidized by an ad hoc subsidy for this project as a pilot programme assessing the possibilities of retrofitting existing inland transport vessels with particulate traps.

The general requirement for the VERS subsidy scheme is to obtain a NOx emission level of 3 g/kWh for existing vessels and 2 g/kWh for new vessels, this over an on-board simulated ISO8178 4-mode test cycle. For the particulate filters the Swiss VERT certification will be regarded as sufficiently stringent to assure consistently low PM emissions. Without such certification additional tests may be required for a filter to control its In-Service efficiency.

In the HD In-Service Testing programme on board tests were executed to gain experience with the test protocol [TNO, 2009] which has been developed in a working group ‘de schone motor voor de binnenvaart’ to control the in-service conformity (VERS) of the vessels equipped with the subsidized SCR systems.
The tests were also executed to asses the real world emission performance of two vessels from the AKZO-Nobel zoutpendel. These vessels had no after treatment installed but are regarded as good candidates for the subsidy scheme. To investigate the emission reduction potential real world engine load profiles have been measured to be able to calculate the total NOx emissions and the potential absolute NOx reduction of the complete fleet of the zoutpendel, consisting of 5 vessels in total.

Furthermore, measurements were performed according to the developed measurement protocol to control the In-Service emission of the first vessel that took part in VERS and has a completely new after treatment system installed. The tests were performed after at least 100h of de-greening of the system. After at least 1000h of operation another test will be done to check the durability of the emission reduction systems.

3.9 Eurisec

For Member States, who have goals to reduce air-pollution and emission of greenhouse gases, not only the emission performance over the legislative test procedure is found to be important, they also have great interest in the actual reduction of the In-Service emissions. As until now In-Service Conformity checking according to the official procedure is not found to be a robust legislative tool, some Member States took the initiative to organize emission testing programmes themselves in which the Emission performance of engines or vehicles In-Service is checked.

Recently, in the EU directives more influential power was given to results of Member State programmes and possibly in the future such influence will be further enhanced by new provisions taken in EU emission legislation.

For HD emission legislation from 2005/78/EC, Annex III paragraph 3.5; A Member State may conduct it's own surveillance testing, and 3.6; The type-approval authority may take up surveillance testing conducted and reported by a Member State as a basis for the decisions according to section 3.4.
Further enhancements are expected to make the inclusion of results from MS programmes mandatory.

Already 13 years ago Member States showed initiatives to start programmes to monitor the emission performance of HD engines over time. At the moment, in the EU, two national or so called Member State programmes are running for HD engines:

1. Sweden; for Vägverket, the Swedish Road Administration, the national authority assigned the overall responsibility for the entire (Swedish) road transport system [Vägverket, 2008]
2. Netherlands; for the Dutch ministry of Spatial Planning, Public Housing and the Environment

For LD vehicles programmes are running for the same MS as above, added with the programme for United Kingdoms Department for Transport.

Representatives of the Member States share the opinion that a platform is desirable where information regarding In Service Conformity is shared. The Eurisec group is such a platform. Goals of the group are to:

- discuss results
- share information
- complement ones programmes and
- increase impact and reach

The group meets at least two times a year and other Member States are also invited to join and contribute.

Results of programmes are published on a common website of the working group; www.eurisec.eu

4 References

[Bijsterbosch, 1993] Bijsterbosch, B.J.: *Eindrapport Pilotsteekproef Vrachtwagens* (Final report pilot in-use compliance project trucks), TNO-report 93.OR.VM.055.1/BJB

[Bijsterbosch, 1995] Bijsterbosch, B.J.: *Eindrapport steekproefcontrole programma vrachtwagens 1994-1995* (Final report in-use compliance project trucks), TNO-report 95.OR.VM.015.1/BJB, 1995.

[DG ENTR, 2007] PORTABLE EMISSION MEASUREMENT SYSTEMS (PEMS) HEAVY-DUTY PILOT PROGRAMME, FINAL PROJECT PLAN 2007

[DG JRC, 2007] Bonnel P. et al. GUIDE FOR THE PREPARATION AND THE EXECUTION OF EMISSIONS ROAD TESTS ON HEAVY-DUTY VEHICLES *DRAFT VERSION 3 - EU-PEMS PROJECT PILOT PROGRAM*

[DG JRC, 2009] Bonnel P. et al. EVALUATION OF PASS-FAIL METHODS FOR HEAVY-DUTY EMISSIONS COMPLIANCE TESTING BASED ON PEMS *EU-PEMS PROJECT - TASK 3 REPORT*

[Gompel, 1993] Van Gompel, P. and R.Verbeek: *Eindrapport Diesel-controle methode; Procedure en nauwkeurigheid van testen, volgens Richtlijnen 88/77/EEG en 72/306/EEG, uitgevoerd op een rollenbank* (Final report DCM; Procedure and accuracy of testing, according to 88/77/EEC and 72/306/EEC, carried out at a chassis dynamometer), TNO-report 93.OR.VM.023.1/PvG/RV, 1993.

[Jordaan 2000] Jordaan, K.H.: *Steekproefcontroleprogramma Vrachtwagens 2001-2003 - Update correlatie-onderzoek ESC testcyclus motorproefstand-rollenbank* (In-use compliance programme trucks 2001-2003 - Update correlation check ESC test cycle engine testbed versus chassis dynamometer) TNO-report 00.OR.VM.029.1/KJ.

[PMP, 2009] http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmp23.html

[Riemersma, 2000] Riemersma, I.J. et al.: *Steekproefcontroleprogramma Vrachtwagens 1998-2000* (In-use compliance programme trucks 1998-2000), TNO-report 00.OR.VM.076.1/IJR

[Riemersma, 2006] Riemersma, I.J. et al.:*In-use compliance programme trucks 2001 – 2004,*TNO-report 06.OR.VM.019.1/IJR

[Riemersma, 2009] Riemersma I.J.R. Vermeulen R.J.; Final Report on the In Use Testing Programme for Heavy Duty Vehicles 2001-2006 MON-RPT-033-DTS-2009-00038, 8 januari 2009

[Rijkeboer, 1999] Rijkeboer, R.C. et al.: *Steekproefcontroleprogramma Vrachtwagens 1996-199*" (In-use compliance programme trucks 1996-1997), TNO-report 98.OR.VM.044.1/RSM, 1999.

[TNO 2006; Q1] Riemersma I.J.R. Staats F.; Kwartaalrapportage 1e kwartaal 2006; Steekproefcontroleprogramma Vrachtwagens, 2005, TNO report 06.OR.PT.027.1/IJR, 8 mei 2006

[TNO 2006; Q2] Vermeulen R.J. Vonk W. Staats F.; Kwartaalrapportage 2e kwartaal 2006; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 18 januari 2007

[TNO 2006; Q3] Vermeulen R.J.Vonk W. Kwartaalrapportage 3e kwartaal 2006; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 9 februari 2007

[TNO 2006; Q4] Vermeulen R.J. Vonk W.; Kwartaalrapportage 4e kwartaal 2006; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 15 mei 2007

[TNO 2007; Q1] Vermeulen R.J. Vonk W.; Kwartaalrapportage 1e kwartaal 2007; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 30 augustus 2007

[TNO 2007; Q2] Vermeulen R.J. Vonk W. Op den Brouw M.; Kwartaalrapportage 2e kwartaal 2007; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 19 februari 2008

[TNO 2007; Q3] Vermeulen R.J. Vonk W. Op den Brouw M.; Kwartaalrapportage 3e kwartaal 2007; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-033-01038, 19 maart 2008

[TNO 2007; Q4] Vermeulen R.J. Vonk W. Op den Brouw M.; Kwartaalrapportage 4e kwartaal 2007; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-033-01921, 19 juni 2008

[TNO 2008; Q1] Vermeulen R.J. Eijk A.R.A. Op den Brouw M.; Kwartaalrapportage 1e kwartaal 2008; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-033-02378, 24 juli 2008

[TNO 2008; Q2] Vermeulen R.J. Eijk A.R.A. Op den Brouw M.; Kwartaalrapportage 2e kwartaal 2008; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 25 november 2008

[TNO 2008; Q3] Vermeulen R.J. Eijk A.R.A.; Kwartaalrapportage 3e kwartaal 2008; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-2010-00969, 7 januari 2009

[TNO 2008; Q4] Vermeulen R.J. Eijk A.R.A.; Kwartaalrapportage 4e kwartaal 2008; Steekproefcontroleprogramma Vrachtwagens 2006-2008, TNO report MON-RPT-033-DTS-2009-00197, 26 januari 2009

[TNO 2009; Q1] Vermeulen R.J. Eijk A.R.A.; Kwartaalrapportage 1e kwartaal 2009; Steekproefcontroleprogramma Vrachtwagens 2006-2009, TNO report MON-RPT-2010-00969, 9 juni 2009

[Vonk, 2006] Vonk W. Vermeulen R.J.; Emission Test Results of the Scania DT1211, TNO report 06.OR.PT.052.1/WV, October 25, 2006

[Kadijk, 2008] Kadijk G. Resultaten motortesten met Algae-X fuel conditioner, TNO memorandum MON-MEM-033-DTS-2008-03045, 8 oktober 2008

[TNO 2009] Measurement protocol for the demonstration of the emission performance of In land Waterway Vessels equipped with retrofit SCR and DPF systems

[Vägverket 2008] Almén, J.; Swedish In-Service Testing Programme 2007, on emissions from heavy duty vehicles, report number 2008:122

[Vermeulen, 2007] Vermeulen R.J. Verbeek R.; The efficiency of retrofit diesel particle filters on urban delivery vansMON-RPT-2010-009694 december 2007

[Vermeulen, 2010] Vermeulen R.J.; Praktijk emissiemetingen aan een VDL Ambassador Euro V EEV bus, 2010.

Most relevant legislative documents

2005/55/EC	DIRECTIVE 2005/55/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 September 2005 ...relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles
2005/78/EC	COMMISSION DIRECTIVE 2005/78/EC of 14 November 2005 implementing Directive 2005/55/EC of the European Parliament and ...relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles....thereto
2007/46/EC	DIRECTIVE 2007/46/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles
Regulation 49	UNIFORM PROVISIONS CONCERNING THE MEASURES TO BE TAKEN AGAINST THE EMISSION OF GASEOUS AND PARTICULATE POLLUTANTS FROM COMPRESSION-IGNITION ENGINES FOR USE IN VEHICLES, AND THE EMISSION OF GASEOUS POLLUTANTS FROM POSITIVE-IGNITION ENGINES FUELLED WITH NATURAL GAS OR LIQUEFIED PETROLEUM GAS FOR USE IN VEHICLES

5 Signature

Delft, 2 April 2010

B. Bos

Drs B. Bos
Head of department

TNO Science and Industry

Ing R.J. Vermeulen
Author

A Overview of tested engines/vehicles and specifications

Table 14; Vehicle and engine specifications of the vehicles tested over the ESC on the chassis dynamometer. Vehicle 77 to 79 have been reported in [Riemersma, 2009].

Vehicle code	Leg Cat	Veh make	Veh model	Engine model	Eng. displ.	Prated	Odo reading	Axle config	Emission reduction
					[liter]	[kW]	[km]		
MA76_1	IV (B1)	MAN	TGA 18.390	D2066LF12	10,518	287	74.325	4x2	DOC+PM-kat
SC80_1	IV (B1)	Scania	R124	DT1211	11,705	309	133.500	6x2	EGR
SC80_2	IV (B1)	Scania	R124	DT1211	11,705	309	444.000	4x2	EGR
SC86_1	IV (B1)	Scania	R420 LA 4X2 MNA	DT1212	11,705	309	138.131	4x2	EGR
SC86_2	IV (B1)	Scania	R420 LA 4X2 MNA	DT1212	11,705	309	146.033	4x2	EGR
MA89_1	IV (B1)	MAN	TGA 18.440	D2066LF31	10,518	324	69.730	4x2	DOC+PM-kat
MA89_2	IV (B1)	MAN	TGA 35.440	D2066LF31	10,518	324	105.422	8x4	DOC+PM-kat
MA89_3	IV (B1)	MAN	TGA26.440	D2066LF31	10,518	324	146.058	6x2	DOC+PM-kat
MB79_1	V	Mercedes Benz	Actros	OM501LA.V/3	11,946	300	34.469	4x2	SCR
MB79_2	V	Mercedes-Benz	Actros	OM501LA.V/3	11,946	300	57.822	4x2	SCR
MB82_1b	V (B2)	Mercedes Benz	Axor	OM 457 LA V/3	11,967	300	21.912	4x2	SCR
MB82_2	V (B2)	Mercedes Benz	Axor	OM 457 LA V/3	11,967	300	185.646	4x2	SCR
SC83_1	V ((B2 (D))	Scania	R420	DC1215	11,705	312	71.156	4x2	SCR
SC83_2	V ((B2 (D))	Scania	R420	DC1215	11,705	312	125.961	4x2	SCR
VO84_1	V (B2(D))	Volvo	FH12 FH440 4x2T FAL7.1 RAD-A4	D13A440 EC06B	12,777	324	10.394	4x2	SCR + Clean up (DOC) integrated
VO84_2	V (B2(D))	Volvo	FH12 FH440 4x2T FAL7.1 RAD-A4	D13A440 EC06B	12,777	324	39.134	4x2	SCR + Clean up (DOC) integrated
VO84_3	V (B2(D))	Volvo	FH12 FH440 4X2T FAL7.1 RAD-A4	D13A440 EC06B	12,777	324	41.782	4x2	SCR + Clean up (DOC) integrated
DA87_1	V (B2)	DAF	FT XF105	MX 300S2	12,902	300	187.515	4x2	SCR + Clean up (DOC)
DA87_2	V (B2)	DAF	FT XF105	MX 300S2	12,902	300	78.206	4x2	SCR + Clean up (DOC)
DA87_3	V (B2)	DAF	FT XF105	MX 300S2	12,902	300	87.368	4x2	SCR + Clean up (DOC)
VO88_1	V (B2(	Volvo	FM9 4x2T FAL7.1 RAD-A4	D9B300	9,364	226	33.960	4x2	SCR + Clean up (DOC) integrated

	D))								
VO88_2	V (B2(D))	Volvo	FM9 6X2R FAL9.0	D9B300EC0 6B	9,364	226	50.593	6X2	SCR + Clean up (DOC) integrated
VO88_3	V (B2(D))	Volvo	FM9 4X2R FAL7.5	D9B300EC0 6B	9,364	226	54.320	4x2	SCR + Clean up (DOC) integrated

Table 15; Vehicle and engine specifications of the vehicles tested on the road with a PEMS

Vehicle code	**Leg Cat**	**Veh make**	**Veh model**	**Engine model**	**Eng. displ.**	**Prated**	**Odo reading**	**Axle config**	**Emission reduction**
					[liter]	**[kW]**	**[km]**		
VO90_1	V B2 (D)	Volvo	FE S	D7E320 EC06B	7,146	235	22.223	4x2 Rigid	SCR
IV91	V B2 (D)	Iveco	Stralis	F2BE3681C	7,79	228	24.000	4x2 Rigid	SCR
DA92	V B2 (D)	Daf	CF75	PR228S2	9,186	231	130.125	4x2 Tractor trailer	SCR+ AMOC
SC93	V B2 (G)	Scania	R440	DC13 10	12,74	324	217.434		2-stage EGR
DA94	V B2 (E)	Daf	XF105	MX300S2	12,9	300	92.953	4x2 Tractor trailer	SCR+ AMOC
DA95	V C (I)	Daf	LF45	FR118S3	4,46	117	8.049	4x2 Rigid	SCR+ AMOC?
MB96	V B2 (D)	Mercedes-Benz	Axor	OM457 LA V/3	11,967	295	177.418	4x2 Tractor trailer	SCR
SC97	V B2 (G)	Scania	R420	DC 12 15	11,71	309	143.058	4x2 Tractor trailer	SCR
VD98	V EEV C (I)	VDL-Bus	Ambassador	Cummins ISBe5 225B	6,7	165	42.923	4x2 Bus	SCR + CRT

B Results

B.1 ESC results per engine and per engine type

B.1.1 Results Euro IV: MAN D2066LF12

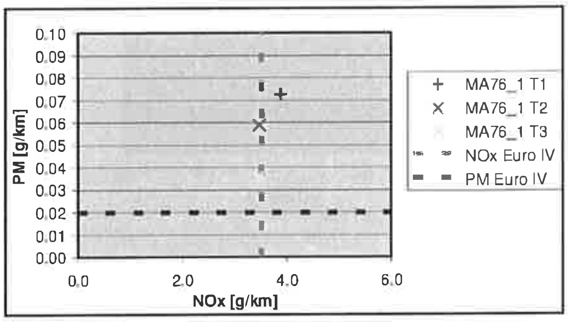
Vehicle engine data

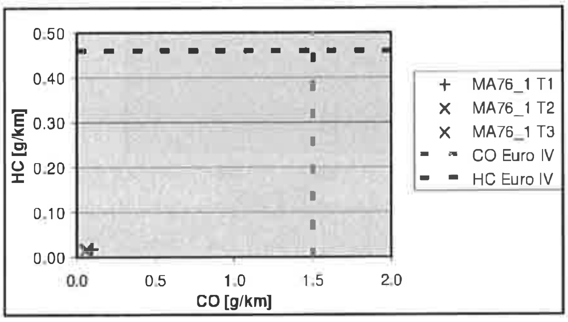
Vehicle/engine brand	MAN
Engine code	D2066LF12
Power rating [kW]	287
Legislative category	Euro IV
After treatment, emission control	- EGR
EC certification#	e4*88/77*2001/27B1*0474*00
TNO test code	MA76_1
Obtained from	
License plate	BP-VB-57
Odometer [km]	74325
Vehicle type	TGA 18.390
State/condition	Good
Remarks	-

Results ESC and NOx points

	MA76_ 1a	MA76_ 1b1	MA76_ 1b2	MA76_ 1b3	Average	TA	Limit	% of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	3,87	3,45	3,45	3,31	3,42	3,02	3,5	101%
PM	0,073	0,059	0,035	0,036	0,051	0,014	0,02	253%
CO	0,093	0,060	0,060	0,050	0,0718	0,096	1,5	4%
HC	0,020	0,020	0,020	0,010	0,016	0,01	0,46	4%
NOx points*	[%]						[%]	
1	104						110	104
2	104						110	104
3	104						110	101

*random NOx points may not exceed 110% of the adjacent test points.





B.1.2 Results Euro IV: MAN D2066LF31

Vehicle/ engine data

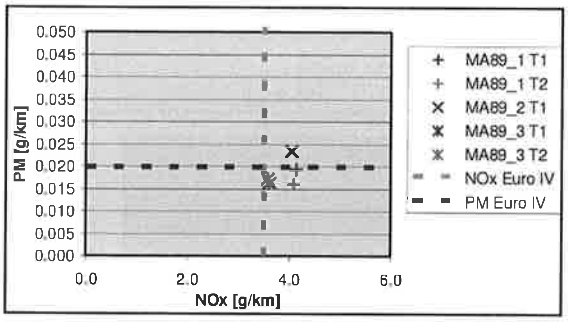
Vehicle/engine brand	MAN
Engine code	D2066LF31
Power rating [kW]	324
Legislative category	Euro IV
After treatment, emission control	DOC, PM-kat, EGR
EC certification#	e4*88/77*2001/27B1*0474*00

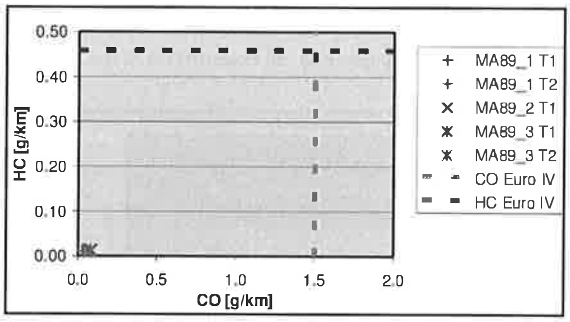
TNO test code	MA89_1	MA89_2	MA89_3
Obtained from	Van Eijck international car rescue	Simon de Feyter b.v.	POST
License plate	BT-DN-76	BS-PX-71	BS-HP-44
Odometer [km]	69730	105422	146058
Vehicle type	TGA 18.440 4X2	TGA 35.440 8X4	TGA26.440 6X2
State/condition	Good	Good	Good
Remarks	-	-	-

Results ESC and NOx points

	MA89_1	MA89_2	MA89_3	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	4,10	4,04	3,58	3,91	3,461	3,5	112
PM	0,018	0,024	0,017	0,019	0,0198	0,02	97
CO	0,034	0,081	0,076	0,064	0,081	1,5	4
HC	0,012	0,013	0,011	0,012	0,014	0,46	3
NOx points*						[%]	
1	102	100	96	99		110	
2	103	98	99	100		110	
3	95	95	102	97		110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.3 Results Euro IV: Scania DT 1211

Vehicle/ engine data

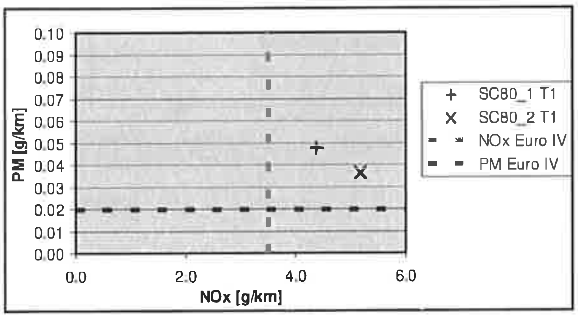
Vehicle/engine brand	Scania
Engine code	DT1211
Power rating [kW]	309
Legislative category	Euro IV
After treatment, emission control	EGR
EC certification#	e4*88/77*2001/27B1*0340*02

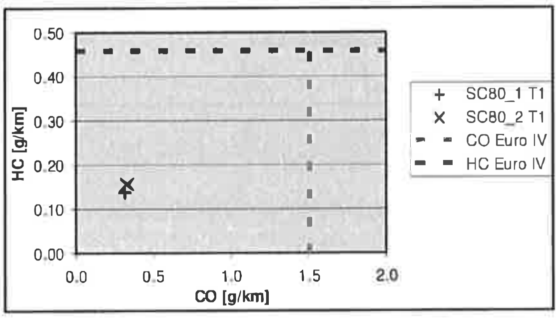
TNO test code	SC80_1	SC80_2
Obtained from	Reinart Internationaal Transport	Maters Huissen B.V.
License plate	WPR 61 YM (Poland)	BP-RL-28
Odometer [km]	133500	444000
Vehicle type	R124 Tractor 4X2	R124 Tractor 4X2
State/condition	Bad	Good
Remarks	High oil consumption Engine oil level at minimum at arrival Revised gear box	-

Results ESC and NOx points

	SC80_1	SC80_2	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	4,38	5,16	4,77	3,40	3,5	136
PM	0,048	0,035	0,042	0,02	0,02	208
CO	0,31	0,33	0,32	0,30	1,5	21
HC	0,14	0,16	0,15	0,10	0,46	32
NOx points*	[%]	[%]	[%]		[%]	
1	115	107	111		110	
2	115	133	124		110	
3	136	142	139		110	

*random NOx points may not exceed 110% of the adjacent test points.





Results Euro IV: Scania DT 1212

Vehicle/ engine data

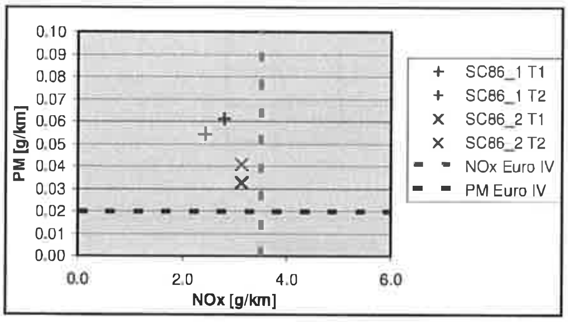
Vehicle/engine brand	Scania
Engine code	DT1212
Power rating [kW]	309
Legislative category	Euro IV
After treatment, emission control	EGR
EC certification#	e4*88/77*2001/27B1*0345*01

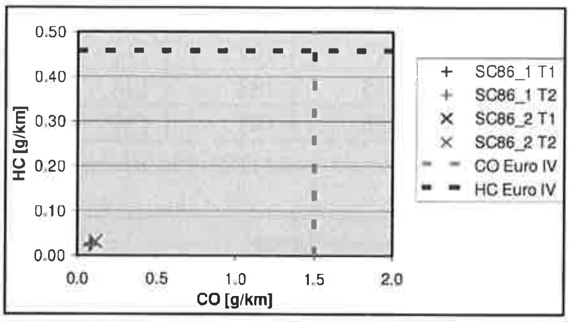
TNO test code	SC86_1	SC86_2
Obtained from	Minnaard Transport	Minnaard Transport
License plate	BS-LB-31	BS-LD-92
Odometer [km]	138131	146033
Vehicle type	R420 LA 4X2	R420 LA 4X2
State/condition	Good	Good
Remarks	ETK number not found on engine	-

Results ESC and NOx points

	SC86_1	SC86_2	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,61	3,12	2,86	3,3	3,5	82
PM	0,058	0,037	0,047	0,01	0,02	237
CO	0,084	0,114	0,099	-	0,5	7
HC	0,025	0,032	0,028	-	0,46	6
NOx points*	[%]	[%]	[%]		[%]	
1	113	108	111		110	
2	117	116	117		110	
3	104	109	107		110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.4 Results Euro V: DAF MX300s2

Vehicle/ engine data

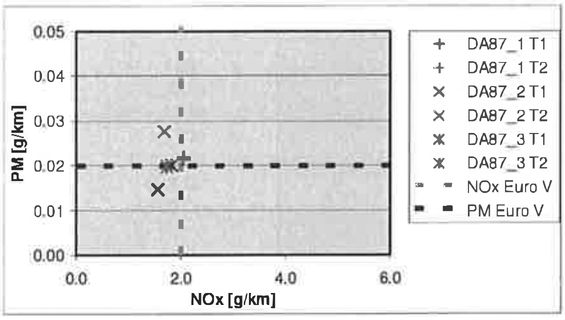
Vehicle/engine brand	DAF
Engine code	MX300S2
Power rating [kW]	300
Legislative category	Euro V
After treatment, emission control	SCR+AMOC
EC certification#	E4*88/77*2001/27B2*0378*00

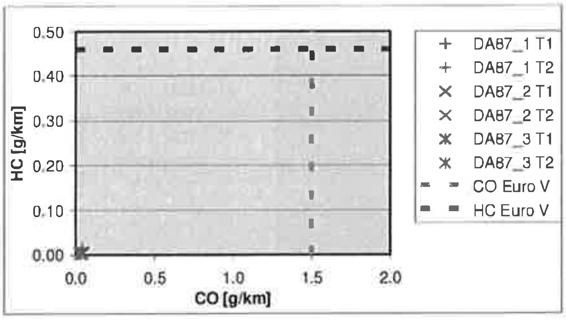
TNO test code	DA87_1	DA87_2	DA87_3
Obtained from	Getru transport	Truck Lease and Rental	Runner Truck Lease
License plate	BS-JJ-90	BS-TF-81	BS-TF-77
Odometer [km]	187515	78206	87368
Vehicle type	FT XF105 4X2	FT XF105 4X2	FT XF105 4X2
State/condition	Good	Good	Good
Remarks	Certification number is outdated, but TA results of outdated file are still valid *Errorcodes: $3d ECU 0: U0441 (Network communicatie groepen) U0113 (Lost communication with emission critical control information) $00 ECU 1: Zie $3d ECU 0.	Certification number is outdated, but TA results of outdated file are still valid Oil cooler; plugged filter	Certification number is outdated, but TA results of outdated file are still valid

Results ESC and NOx points

	DA87_1	DA87_2	DA87_3	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,03	1,61	1,77	1,81	1,80	2,0	90
PM	0,022	0,021	0,020	0,021	0,014	0,02	104
CO	0,04	0,04	0,03	0,04	0,03	1,5	3
HC	0,01	0,01	0,00	0,01	0,05	0,46	2
NOx points*						[%]	
1	167	163	143			110	
2	109	210	120			110	
3	188	139	199			110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.5 Results Euro V: Mercedes Benz OM457 LA V/3

Vehicle/ engine data

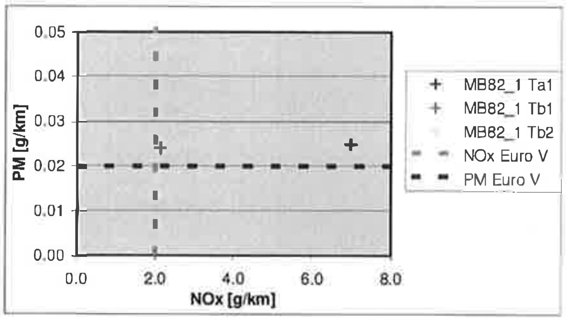
Vehicle/engine brand	Mercedes-Benz
Engine code	OM457 LA V/3
Power rating [kW]	300
Legislative category	Euro V
After treatment, emission control	SCR
EC certification#	e1*88/77*2001/27B2*0607*00

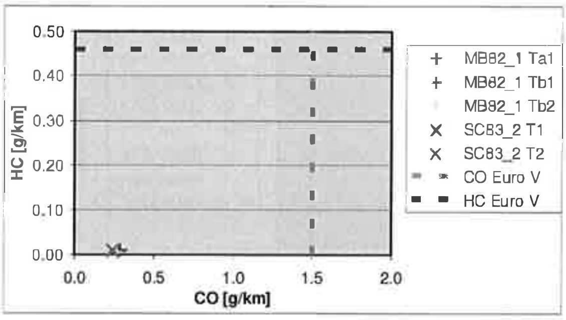
TNO test code	MB82_1a	MB82_1b	MB82_2
Obtained from	Mercedes-Benz Nijkerk	Mercedes-Benz Nijkerk	BATO Beheer
License plate	BR-TD-36	BR-TD-36	BS-ZR-18
Odometer [km]	18551	21912	185645
Vehicle type	Axor 4X2	Axor 4X2	Axor 4X2
State/condition	Good	Good	Good
Remarks	NOx very high; after contact with importer vehicle to Stuttgart) Fuses F12 en F35 removed (ABS and ESP), > text INS on dashboard	Fuses F12 en F35 removed (ABS and ESP), > text INS on dashboard Urea tank replaced from aluminum to plastic type Urea dosage unit replaced ECU replaced	Sludge in hose intercooler out

Results ESC and NOx points

	MB82_1a	MB82_b	MB82_2	Average **1b and 2**	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	6,97	2,07	2,22	2,15	1,58	2,0	108
PM	0,025	0,020	0,012	0,016	0,011	0,02	80
CO	0,15	0,27	0,24	0,25	0,45	1,5	17
HC	0,01	0,01	0,01	0,01	0,01	0,46	2
NOx points*						[%]	
1	103	120	75			110	
2	105	129	102			110	
3	102	112	180			110	

*random NOx points may not exceed 110% of the adjacent test points.





Results Euro V: Mercedes Benz OM501LA V/3

Vehicle/ engine data

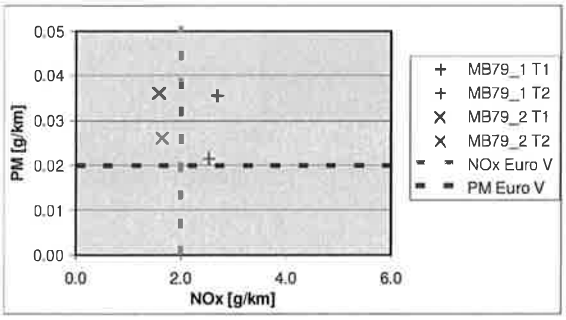
Vehicle/engine brand	Mercedes-Benz
Engine code	OM501 LA V/3
Power rating [kW]	300
Legislative category	Euro V
After treatment, emission control	SCR
EC certification#	????

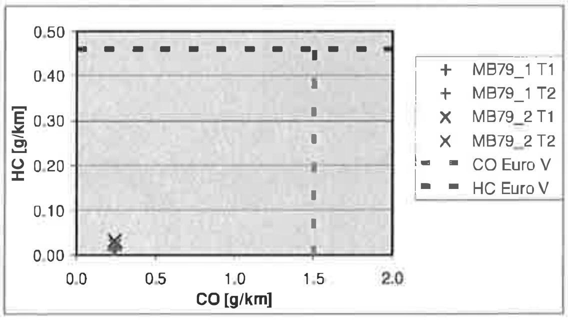
TNO test code	MB79_1	MB79_2
Obtained from	Mercedes-Benz Nijkerk	A.H. Netten
License plate	BR-BB-30	BS-HT-05
Odometer [km]	34469	57822
Vehicle type	Actros 4X2	Actros 4X2
State/condition	Good	Good
Remarks	ASR switched off Urea injection switching intermittently on and off (probably causing high NOx emission) see ESC results of MB79_1 below	-

Results ESC and NOx points

	MB79_1	MB79_2	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,61	1,61	2,11	1,56	2,0	105
PM	0,029	0,031	0,030	0,013	0,02	149
CO	0,24	0,24	0,24	0,27	1,5	16
HC	0,01	0,03	0,021	0,01	0,46	5
NOx points*					[%]	
1	114	80			110	
2	132	85			110	
3	106	107			110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.6 Results Euro V : Scania DC 12 15

Vehicle/ engine data

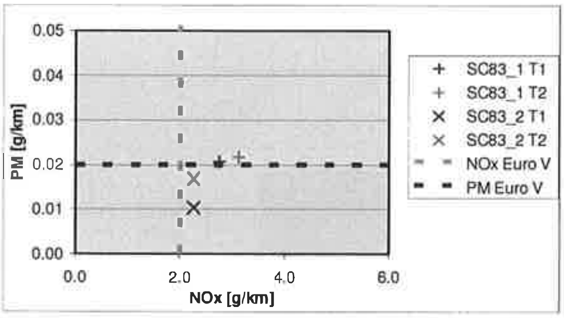
Vehicle/engine brand	Scania
Engine code	DC 12 15
Power rating [kW]	312
Legislative category	Euro V
After treatment, emission control	SCR
EC certification#	E4*2005/55*2005/78D*0036*00

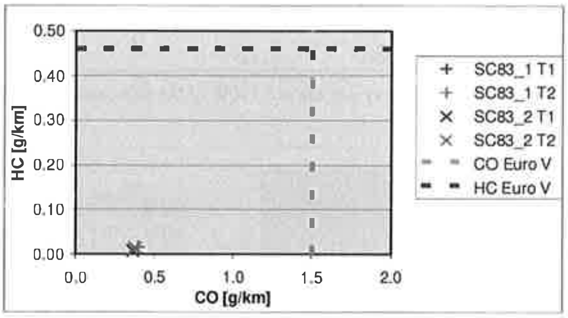
TNO test code	SC83_1	SC83_2
Obtained from	Beers B.V.	BMT Koeriers B.V.
License plate	BS-BF-36	BS-PT-78
Odometer [km]	71156	125961
Vehicle type	R420 4X2	R420 4X2
State/condition	Good	Good
Remarks	-	-

Results ESC and NOx points

	SC83_1	SC83_2	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,94	2,25	2,594	1,90	2,0	130
PM	0,021	0,014	0,017	0,01	0,02	87
CO	0,40	0,37	0,382	0,30	1,5	25
HC	0,02	0,01	0,014	0,15	0,46	3
NOx points*					[%]	
1	58	134			110	
2	102	168			110	
3	61	85			110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.7 Results Euro V: Volvo D13A440 EC06B

Vehicle/ engine data

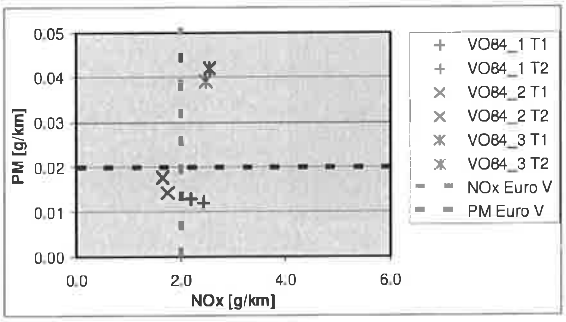
Vehicle/engine brand	Volvo
Engine code	D13A440 EC06B
Power rating [kW]	324
Legislative category	Euro V
After treatment, emission control	SCR+AMOC
EC certification#	E11*2005/55*2006/51D*2001*02

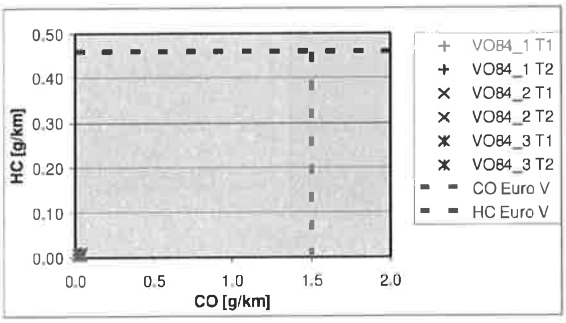
TNO test code	VO84_1	VO84_3	VO84_3
Obtained from	BAS Groep	WD Trucks	Runner Truck Lease
License plate	BS-RH-66	BS-TL-90	BS-SL-92
Odometer [km]	10394	39134	41782
Vehicle type	FH440 4X2	FH440 4X2	FH440 4X2
State/condition	good	good	good
Remarks	Error air-system	-	Vibration at 1500 rpm; one injector replaced before tests

Results ESC and NOx points

	VO84_1	VO84_3	VO84_3	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,30	1,69	2,51	2,164	1,74	2,0	108
PM	0,013	0,016	0,041	0,023	0,014	0,02	115
CO	0,02	0,02	0,04	0,027	0,12	1,5	2
HC	0,01	0,01	0,01	0,007	0,00	0,46	2
NOx points*						[%]	
1	73	80	89			110	
2	57	59	64			110	
3	85	80	89			110	

*random NOx points may not exceed 110% of the adjacent test points.





B.1.8 Results Euro V: Volvo D9B300EC06B

Vehicle/ engine data

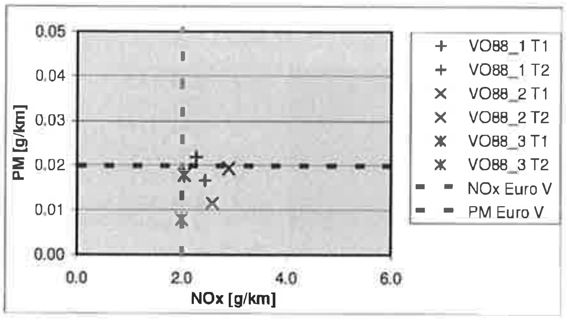
Vehicle/engine brand	Volvo
Engine code	D9B300EC06
Power rating [kW]	226
Legislative category	Euro V
After treatment, emission control	SCR+AMOC
EC certification#	E2*2005/55*2006/51D*06015*01

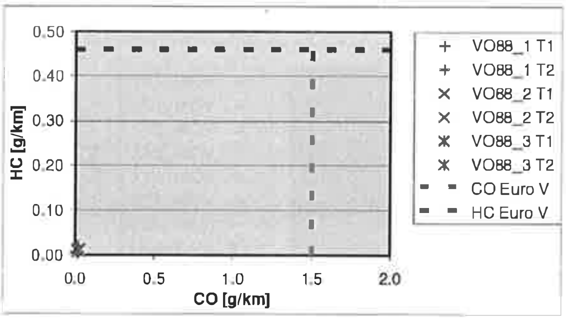
TNO test code	VO88_1	VO88_2	VO88_3
Obtained from	Int transportbedrijf G. Kuijf	Ton van Bergen Holding	Vonk en Co
License plate	BT-GT-74	BS-VN-08	BT-DJ-87
Odometer [km]	33960	50866	
Vehicle type	FM9 4X2	FM9 4X2	FM9 4X2
State/condition	good	good	good
Remarks	A high NH3 slip was noted during a pre-check (A100; 34ppm, B100; 96ppm, C100; 70ppm). Rest of tests ok (<4ppm)	-	-

Results ESC and NOx points

	VO88_1	VO88_2	VO88_3	Average	TA	Limit	%-of limit
	[g/kWh]	[g/kWh]	g/kWh]	[g/kWh]	[g/kWh]	[g/kWh]	[%]
NOx	2,35	2,73	2,02	2,367	0,85	2,0	118
PM	0,019	0,016	0,013	0,016	0,011	0,02	80
CO	0,01	0,02	0,02	0,020	0,04	1,5	1
HC	0,01	0,01	0,01	0,012	0,01	0,46	3
NOx points*						[%]	
1	109	93	79			110	
2	100	103	76			110	
3	108	93	111			110	

*random NOx points may not exceed 110% of the adjacent test points.





B.2 Results PEMS

B.2.1 Results PEMS: Volvo FE S; D7E320 EC06B

Vehicle and engine specifications

TNO Testing Code			VO90
Vehicle	Brand		Volvo
	Vehicle Type		FE S 4X2R
	Odometer	[km]	22223
	Configuration		rigid truck 4x2
	Duty		distribution
	License plate		BS-ZF-71
	EC TA number		e1*2005/55*2005/78D*0696800
Engine	Engine type		D7E320 EC06B
	Power	[kW]	235
	Engine Displ	[l]	7,146
	Leg Cat		Euro V
	Emission Control		SCR
	Fuel		EN590, market

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3
Test sequence		n.t.	n.t.	1	2	3
Distance	[km]			65,427	59,597	60,051
Avg veh speed	[km/h]			31,1	36,200	39,800
Ambient T	[ºC]			28	27,0	27,0
Veh weight / load / total / load-%	[t / t / t / %]			9.5 / 3.3 / 12.8 / 30	9.5 / 3.3 / 12.8 / 30	9.5 / 3.3 / 12.8 / 30
Nox corr	[g/kW.h]			4,58	3,23	3,23
HC	[g/kW.h]			0	0,00	0,00
CO	[g/kW.h]			0,74	0,85	1,29
CO2	[g/kW.h]			716	721	696
bsfc	[g/kW.h]			232	228	220
Nox corr	[g/km]			4,84	3,45	3,55
NO2 mass fraction	[%]			12,2	10,6	10,6
HC	[g/km]			0	0,00	0,00
CO	[g/km]			0,78	0,91	1,41
CO2	[g/km]			775	770	765
FC	[l/100km]			29,14	29,0	28,8
NOx MAX uncorr	[g/kW.h]					
HC MAX	[g/kW.h]					
CO MAX	[g/kW.h]					
Work	[kW.h]			36,8	36,8	38,3
pass-fail settings	power threshhold work Emroad version					
Remarks				TNT distribution cycle	TNT distribution cycle	TNT distribution cycle

B.2.2 Results PEMS: Iveco Stralis; F2BE3681C

Vehicle and engine specifications

TNO Testing Code			IV91
Vehicle	Brand		Iveco
	Vehicle Type		AT190S31/P
	Odometer	[km]	24000
	Configuration		rigid truck 2x2
	Duty		distribution
	License plate		BT-TJ-41
	EC TA number		E3*2005/55*2005/78D*1028/01
Engine	Engine type		F2BE3681C
	Power	[kW]	228
	Engine Displ	[l]	7,79
	Leg Cat		Euro V
	Emission Control		SCR, NH3 Slipcat
	Fuel		EN590, market

		Ref loaded	Ref un loaded	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9
Test sequence		2	1	3	4	5	6	7	8	9	10	11
Distance	[km]	70,0	70,6	n.a.	133,9	59,1	4,9	15,9	n.a.	34,4	16,3	105,8
Avg veh speed	[km/h]	39,9	28,2	n.a.	75,7	33,6	6,9	41,4	n.a.	32,3	16,5	57,2
Ambient T	[ºC]	2,8	8,3	n.a.	-1,5	-0,7	-0,1	0,0	n.a.	2,1	3,5	4,1
Veh weight / load / total / load-%	[t / t / t / %]	9,8 / 6,55 / 16,4 / 50	9,8 / 0 / 9,8 / 0	n.a.	9,8 / 6,55 / 16,4 / 50	9,8 / 6,55 / 16,4 / 50	9,8 / 6,55 / 16,4 / 50	9,8 / 6,55 / 16,4 / 50	n.a.	9,8 / 6,55 / 16,4 / 50	9,8 / 6,55 / 16,4 / 50	9,8 / 6,55 / 16,4 / 50
Nox corr	[g/kW.h]	3,45	4,95	n.a.	2,91	3,61	3,25	3,39	n.a.	2,99	3,13	1,71
HC	[g/kW.h]	0,00	0,01	n.a.	0,00	0,03	0,04	0,04	n.a.	0,02	0,06	0,01
CO	[g/kW.h]	1,54	2,20	n.a.	1,14	1,47	1,20	1,57	n.a.	0,88	1,27	0,71
CO2	[g/kW.h]	737	710	n.a.	763	703	417	722	n.a.	437	424	456
bsfc	[g/kW.h]	232	225	n.a.	240	222	132	228	n.a.	138	134	144
Nox corr	[g/km]	3,42	4,69	n.a.	2,18	4,22	7,99	4,15	n.a.	5,39	7,30	2,55
NO2 mass fraction	[%]	0,4	2,4	n.a.	3,7	0,9	2,7	0,70	n.a.	1,9	1,5	2,4
HC	[g/km]	0,00	0,01	n.a.	0,00	0,04	0,10	0,05	n.a.	0,03	0,13	0,02
CO	[g/km]	1,53	2,09	n.a.	0,86	1,71	2,94	1,91	n.a.	1,58	2,97	1,06
CO2	[g/km]	732	672	n.a.	573	821	1026	882	n.a.	788	991	678
FC	[l/100km]	27,5	25,4	n.a.	21,5	30,8	38,6	33,1	n.a.	29,6	37,2	25,4
NOx MAX uncorr	[g/kW.h]	3,43		n.a.	3,54					3,52		2,19
HC MAX	[g/kW.h]	0,01		n.a.	0,01					0,02		0,02
CO MAX	[g/kW.h]	1,42		n.a.	1,22					0,94		0,84
Work	[kW.h]	38,8		n.a.	38,8					38,8		38,8
pass-fail settings	power threshhold work Emroad version	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks			P<20%	test error		P<20%	work<<	work<<	test error		work<<	

B.2.3 Results PEMS: DAF CF75; PR228S2

Vehicle and engine specifications

TNO Testing Code			DA92
Vehicle	Brand		DAF
	Vehicle Type		FT CF75
	Odometer	[km]	130125
	Configuration		2x2
	Duty		distribution
	License plate		BS-XZ-01
	EC TA number		E4*2005/55*2005/78D*0020*00
Engine	Engine type		PR228S2
	Power	[kW]	231
	Engine Displ	[l]	9,186
	Leg Cat		Euro V
	After treatment		SCR
	Fuel		EN590, market fuel

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3	Rep 4
Test sequence		2	1	3	4	5	6
Distance	[km]	73,2	73,3	165,3	36,8	72,3	112,7
Avg veh speed	[km/h]	34,8	38,6	57,0	36,7	40,4	49,9
Ambient T	[ºC]	4,0	5,8	2,4	2,8	3,3	3,2
Veh weight / load / total / load-%	[t / t / t / %]	12,3 / 7,6 / 19,9	12,3 / 0 / 12,3	12,3 / 7,6 / 19,9	12,3 / 7,6 / 19,9	12,3 / 7,6 / 19,9	12,3 / 7,6 / 19,9
Nox corr	[g/kW.h]	3,91	4,30	3,88	3,69	3,92	3,65
HC	[g/kW.h]	0,03	0,06	0,08	0,08	0,07	0,09
CO	[g/kW.h]	2,17	2,48	2,07	2,54	2,04	2,02
CO2	[g/kW.h]	516	486	538	545	531	535
bsfc	[g/kW.h]	**163**	**154**	**170**	**172**	**168**	**169**
Nox corr	[g/km]	6,78	6,17	5,22	6,26	6,17	5,27
NO2 mass fraction	[%]	2,5	1,1	1,3	0,3	0,6	1,1
HC	[g/km]	0,06	0,09	0,10	0,13	0,12	0,13
CO	[g/km]	3,77	3,55	2,79	4,32	3,21	2,92
CO2	[g/km]	895	698	723	925	837	773
FC	[l/100km]	33,6	26,3	27,2	34,8	31,5	29,1
NOx MAX uncorr	[g/kW.h]	4,95	5,39	5,61	4,21	4,84	5,35
HC MAX	[g/kW.h]	0,08	0,08	0,12	0,08	0,08	0,13
CO MAX	[g/kW.h]	2,58	2,83	2,68	2,81	2,54	2,42
Work	[kW.h]	39,3	39,3	39,3	39,3	39,3	39,3
pass-fail settings	power thresh hold work Emroad version	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks		low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?

B.2.4 Results PEMS: Scania R440; DC13 10

Vehicle and engine specifications

TNO Testing Code			SC93
Vehicle	Brand		Scania
	Vehicle Type		R440 A
	Odometer	[km]	217434
	Configuration		Tractor Trailer
	Duty		Long haulage
	License plate		BT-PL-50
	EC TA number		E4*2005/55*2006/81G*0085*00
Engine	Engine type		DC13 10
	Power	[kW]	326
	Engine Displ	[l]	12,74
	Leg Cat		Euro V
	Emission Control		EGR 2-stage
	Fuel		EN 590, market fuel

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3	Ref unloaded 2
Test sequence		1	5	2	3	4	6
Distance	[km]	73,095	71,686	141,457	154,586	96,750	70,527
Avg veh speed	[km/h]	36,8	42,2	62,2	74,1	57,5	46,7
Ambient T	[ºC]	11,1	11,0	9,8	9,4	12,3	12,9
Veh weight / load / total / load-%	[t / t / t / %]	17 / 12 / 29 / 50	17 / 0 / 17 / 0	17 / 12 / 29 / 50	17 / 12 / 29 / 50	17 / 12 / 29 / 50	17 / 0 / 17 / 0
Nox corr	[g/kW.h]	3,02	9,86	2,58	2,28	4,70	3,87
HC	[g/kW.h]	0,15	0,18	0,14	0,10	0,15	0,19
CO	[g/kW.h]	1,10	1,32	0,95	0,85	1,08	1,23
CO2	[g/kW.h]	564	552	576	586	564	576
bsfc	[g/kW.h]	178	175	182	185	179	182
Nox corr	[g/km]	6,45	15,78	4,14	3,72	6,78	6,08
NO2 mass fraction	[%]	9,1	6,8	8,8	8,1	7,7	8,5
HC	[g/km]	0,32	0,29	0,23	0,17	0,21	0,29
CO	[g/km]	2,36	2,11	1,52	1,38	1,56	1,94
CO2	[g/km]	1206	884	922	955	814	905
FC	[l/100km]	45,4	33,2	34,7	35,9	30,7	34,0
NOx MAX uncorr	[g/kW.h]	3,46	11,98	3,68	3,33	8,16	7,08
HC MAX	[g/kW.h]	0,14	0,18	0,17	0,12	0,18	0,20
CO MAX	[g/kW.h]	1,10	1,38	1,32	0,96	1,32	1,41
Work	[kW.h]	55,4	55,4	55,4	55,4	55,4	55,4
pass-fail settings	power thresh hold work Emroad version	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks		low bsfc engine work to high?	OBD emission error (ref unloaded2) low bsfc engine work to high?	low bsfc engine work to high?		OBD emission error low bsfc engine work to high?	OBD emission error (ref unloaded) low bsfc engine work to high?

B.2.5 *Results PEMS: DAF XF105; MX300S2*

Vehicle and engine specifications

TNO Testing Code			DA94
Vehicle	Brand		DAF
	Vehicle Type		XF105
	Odometer	[km]	92953
	Configuration		Tractor Trailer
	Duty		Long Haul
	License plate		BT-ZZ-33
	EC TA number		E4*2005/55*2006/81E*0018*02
Engine	Engine type		MX300S2
	Power	[kW]	300
	Engine Displ	[l]	12,9
	Leg Cat		Euro V
	Emission Control		SCR + AMOC
	Fuel		EN590, market

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Ref loaded 2	Ref loaded 3
Sequence		1	8	4	5	6	7	9	10	11	2	3
Distance	[km]	72,070	72,132	100,990	164,056	46,823	35,540	102,229	112,387	164,411	71,978	72,004
Avg veh speed	[km/h]	35,2	37,6	49,4	56,1	59,8	38,2	38,6	56,2	71,6	37,4	42,6
Ambient T	[ºC]	11,6	24,4	8,9	11,9	17,3	20,6	13,5	12,5	13,4	15,7	17,3
Veh weight / load / total / load-%	[t / t / t / %]	15.8 / 13.8 / 29.6 / 50	15.8 / 0 / 15.8 / 0	15.8 / 13.8 / 29.6 / 50	15.8 / 13.8 / 29.6 / 50	15.8 / 13.8 / 29.6 / 50	15.8 / 13.8 / 29.6 / 50	15.8 / 33.5 / 49.3 /100	15.8 / 33.5 / 49.3 /100	15.8 / 33.5 / 49.3 /100	15.8 / 13.8 / 29.6 / 50	15.8 / 13.8 / 29.6 / 50
Nox corr	[g/kW.h]	2,55	3,14	3,45	2,08	1,97	3,23	2,68	1,88	1,82	4,80	5,23
HC	[g/kW.h]	0,02	0,01	0,02	0,02	0,01	0,01	0,00	0,00	0,00	0,02	0,02
CO	[g/kW.h]	1,47	1,47	1,15	0,83	0,93	1,07	0,68	0,53	0,46	0,65	1,55
CO2	[g/kW.h]	507	443	520	498	483	516	527	513	527	370	511
bsfc	[g/kW.h]	160	140	164	157	153	163	167	162	166	116	161
Nox corr	[g/km]	5,86	5,96	6,55	3,88	3,49	6,78	6,82	3,90	3,61	13,34	11,36
NO2 mass fraction	[%]	5,0	6,1	6,5	8,9	10,7	6,3	7,1	10,3	10,7	6,4	7,8
HC	[g/km]	0,05	0,03	0,03	0,04	0,02	0,03	0,01	0,00	0,00	0,05	0,05
CO	[g/km]	3,39	2,78	2,17	1,54	1,65	2,25	1,73	1,09	0,91	1,80	3,37
CO2	[g/km]	1167	842	987	928	855	1083	1343	1067	1042	1029	1109
FC	[l/100km]	43,7	31,7	37,1	34,9	32,1	40,7	50,5	40,2	39,2	38,5	41,6
NOx MAX uncorr	[g/kW.h]	3,63	4,63	4,62	4,41	2,49	5,18	4,69	2,90	3,10	5,75	6,41
HC MAX	[g/kW.h]	0,04	0,03	0,05	0,04	0,01	0,02	0,02	0,01	0,01	0,04	0,05
CO MAX	[g/kW.h]	2,28	1,85	1,91	1,57	1,26	1,42	1,29	0,68	0,78	0,95	2,43
Work	[kW.h]	39,3	39,3	39,3	39,3	39,3	39,3	39,3	39,3	39,3	39,3	39,3
pass-fail settings	power thresh hold work Emroad	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks		low bsfc engine work >?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	low bsfc engine work to high?	100% pay load low bsfc engine work to high?	100% pay load low bsfc engine work to high?	100% pay load low bsfc engine work to high?	no adblue low bsfc engine work to high?	no ad blue but water low bsfc engine work to high?

B.2.6 Results PEMS, DAF LF45; FR118S3

Vehicle and engine specifications

TNO Testing Code			DA95
Vehicle	Brand		DAF
	Vehicle Type		LF45
	Odometer	[km]	8049
	Configuration		Rigid truck
	Duty		Distribution
	License plate		BV-SV-44
	EC TA number		E11*2005/55*2006/51I*2115*00
Engine	Engine type		FR118S3
	Power	[kW]	117
	Engine Displ	[l]	4,46
	Leg Cat		Euro V
	Emission Control		SCR
	Fuel		EN590, market

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3	Rep 4	Ref loaded2	Ref loaded3	Ref loaded4	Ref unloaded2
Sequence		1	4	6	7	8	9	2	3	10	5
Distance	[km]	72,01	72,059	96,883	61,770	69,559	18,470	72,059	72,145	72,065	71,749
Avg veh speed	[km/h]	38,45	39,4	51,0	31,0	36,3	30,9	44,9	38,6	39,6	40,1
Ambient T	[ºC]	14,60	15,9	13,6	16,4	20,1	21,6	18,9	13,7	14,7	19,1
Veh weight / load / total / load-%	[t / t / t / %]	5.58 / 1 / 6.58 / 50	5.58 / 0 / 5.58 / 0	5.58 / 1 / 6.58 / 50	5.58 / 1 / 6.58 / 50	5.58 / 1 / 6.58 / 50	5.58 / 1 / 6.58 / 50	5.58 / 1 / 6.58 / 50	5.58 / 2 / 7.58 / 100	5.58 / 2 / 7.58 / 100	5.58 / 0 / 5.58 / 0
Nox corr	[g/kW.h]	5,70	6,06	4,05	6,23	5,28	6,60	5,91	4,25	8,54	5,52
HC	[g/kW.h]	0,02	0,01	0,01	0,02	0,01	0,02	0,00	0,02	0,01	0,02
CO	[g/kW.h]	1,12	1,08	1,03	0,89	0,70	0,82	0,84	1,19	1,05	1,40
CO2	[g/kW.h]	584	572	579	552	538	569	565	565	571	577
bsfc	[g/kW.h]	184,79	181	183	174	170	179	178	179	180	182
Nox corr	[g/km]	4,17	3,77	2,78	4,53	3,44	4,58	3,82	3,06	6,12	3,51
NO2 mass fraction	[%]	1,70	1,3	1,4	2,2	1,3	1,6	1,54	2,10	2,00	1,80
HC	[g/km]	0,01	0,01	0,01	0,01	0,01	0,02	0,00	0,02	0,01	0,01
CO	[g/km]	0,82	0,67	0,71	0,65	0,46	0,57	0,54	0,85	0,75	0,89
CO2	[g/km]	427,31	356	398	401	350	395	366	406	409	367
FC	[l/100km]	16,09	13,4	15,0	15,1	13,1	14,8	13,7	15,3	15,4	13,8
NOx MAX uncorr	[g/kW.h]	7,69	7,53	5,43	6,49	5,62	0,00	8,33	4,73	9,93	6,40
HC MAX	[g/kW.h]	0,02	0,02	0,02	0,02	0,01	0,00	0,00	0,02	0,02	0,01
CO MAX	[g/kW.h]	1,14	1,20	1,41	0,90	0,79	0,00	0,96	1,03	1,01	1,23
Work	[kW.h]	19,80	19,8	19,8	19,8	19,8	0,0	19,8	19,8	19,8	19,8
pass-fail settings	power thresh hold work Emroad	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks		low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	additional test low bsfc engine work >?	pay load 100% low bsfc engine work >?	no adblue low bsfc engine work >?	additional test low bsfc engine work >?

B.2.7 Results PEMS: Mercedes Benz Axor; OM457 LA V/3

Vehicle and engine specifications

TNO Testing Code			MB96
Vehicle	Brand		Mercedes Benz
	Vehicle Type		Axor 1840LS
	Odometer	[km]	177418
	Configuration		Tractor Trailer
	Duty		Long Haulage/distribution
	License plate		BS-NT-83
	EC TA number		E1*88/77*2001/27B2*0607*00
Engine	Engine type		OM457 LA V/3
	Power	[kW]	295
	Engine Displ	[l]	11,967
	Leg Cat		Euro V
	Emission Control		SCR
	Fuel		EN590, market

Results not available due to non accessible CAN data.

B.2.8 Results PEMS: Scania R420a; DC 12 15

Vehicle and engine specifications

TNO Testing Code			SC97
Vehicle	Brand		Scania
	Vehicle Type		R420a
	Odometer	[km]	143058
	Configuration		Tractor trailer
	Duty		Long Haulage/distribution
	License plate		BT-NZ-05
	EC TA number		E4*2005/55*2006/81G*0102*01
Engine	Engine type		DC 12 15
	Power	[kW]	309
	Engine Displ	[l]	11,71
	Leg Cat		Euro V
	Emission Control		SCR
	Fuel		EN590, market

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3
Test sequence		5	1	2	3	4
Distance	[km]	68,244	72,533	152,968	42,804	139,748
Avg veh speed	[km/h]	33,9	37,9	58,8	24,3	63,4
Ambient T	[ºC]	18,2	21,0	15,4	17,9	17,5
Veh weight / load / total / load-%	[t / t / t / %]	17.8 / 12 / 29.8 / 50	17.8 / 0 / 17.8 / 0	17.8 / 12 / 29.8 / 50	17.8 / 12 / 29.8 / 50	17.8 / 12 / 29.8 / 50
Nox corr	[g/kW.h]	3,13	4,83	3,64	3,74	3,56
HC	[g/kW.h]	0,05	0,08	0,03	0,05	0,06
CO	[g/kW.h]	4,11	2,06	2,14	2,12	2,40
CO2	[g/kW.h]	544	509	578	484	559
bsfc	[g/kW.h]	172	160	182	153	176
Nox corr	[g/km]	6,25	7,03	5,11	7,19	4,66
NO2 mass fraction	[%]	0,6	0,6	1,1	1,2	0,5
HC	[g/km]	0,10	0,12	0,05	0,10	0,07
CO	[g/km]	8,20	3,00	3,00	4,07	3,14
CO2	[g/km]	1087	740	811	931	732
FC	[l/100km]	40,8	27,8	30,5	35,0	27,5
NOx MAX uncorr	[g/kW.h]	3,50	5,10	4,52	3,88	4,55
HC MAX	[g/kW.h]	0,07	0,09	0,07	0,05	0,06
CO MAX	[g/kW.h]	4,87	2,33	3,18	2,34	2,73
Work	[kW.h]	53,2	53,2	53,2	53,2	53,2
pass-fail settings	power thresh hold work Emroad version	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80
Remarks		low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?	low bsfc engine work >?

B.2.9 Results PEMS: VDL Ambassador; Cummins ISBe5 225B

Vehicle and engine specifications

TNO Testing Code			VD98
Vehicle	Brand		VDL
	Vehicle Type		Bus
	Odometer	[km]	42923
	Configuration		Standard bus SB200EEV
	Duty		City and agglomeration
	License plate		BV-DF-76
	EC TA number		E4*2005/55*2006/81I*0051*01
Engine	Engine type		Cummins ISBe5 225B
	Power	[kW]	165
	Engine Displ	[l]	6.7
	Leg Cat		Euro V EEV
	Emission Control		SCR+CRT
	Fuel		EN590, market

		Ref loaded	Ref unloaded	Rep 1	Rep 2	Rep 3	Special cases		
		n.t.	n.t.				SORT 1	SORT 2	SORT 3
Test sequence				1	2	3	3	4	5
Distance	[km]			23,252	52,463	31,869	0,493	0,880	1,397
Avg veh speed	[km/h]			38,3	23,6	22,4	12,50	19,10	28,30
Ambient T	[ºC]			23	19	21	22	22	22
Veh weight / load / total / load-%	[t / t / t / %]			9 / 3 / 12 / 50	9 / 3 / 12 / 50	9 / 3 / 12 / 50	9 / 3 / 12 / 50	9 / 3 / 12 / 50	9 / 3 / 12 / 50
Nox corr	[g/kW.h]			0,99	1,26	1,70			
HC	[g/kW.h]			0,01	0,01	0,04			
CO	[g/kW.h]			0,61	0,36	0,44			
CO2	[g/kW.h]			509,75	493,17	495,35			
bsfc	[g/kW.h]			161,85	156,73	157,45			
Nox corr	[g/km]			1,32	2,19	2,86	11,30	6,19	3,60
NO2 mass fraction	[%]			40,6	32,0	45,2	34,6	29,0	28,6
HC	[g/km]			0,01	0,01	0,07	0,00	0,03	0,00
CO	[g/km]			0,81	0,62	0,73	1,20	1,00	0,70
CO2	[g/km]			678	855	832	1218	961	866
FC	[l/100km]			25,6	32,4	31,5	46,1	36,3	32,7
NOx MAX uncorr	[g/kW.h]			0,99	1,88	1,86			
HC MAX	[g/kW.h]			0,01	0,01	0,05			
CO MAX	[g/kW.h]			0,62	0,41	0,46			
Work	[kW.h]			27,1	27,1	27,1			
pass-fail settings	power thresh hold work Emroad version			20% 3XETC 3.80	20% 3XETC 3.80	20% 3XETC 3.80			
Remarks				Utrecht, lijn 63 low bsfc engine work >?	Utrecht, lijn 74 low bsfc engine work >?	Utrecht, lijn 77 low bsfc engine work >?	average of 5 SORT 1 sequences	average of 6 SORT 2 sequences	average of 5 SORT 3 sequences

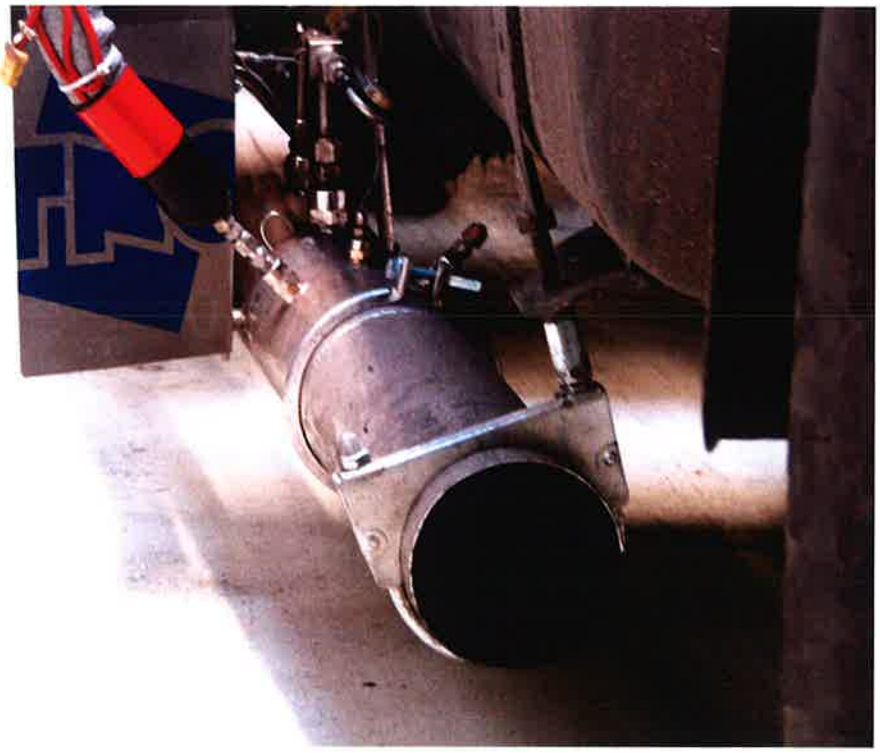
C The test methodology used; PEMS

C.1 Equipment

The following equipment used:

- Semtech DS
- Semtech Exhaust Flow Meter (EFM II)
- Connection box to ECM for engine/vehicle signals (CAN; mostly SAE J1939)
- a generator set so that the PEMS can operate stand alone (Honda EU20i)
- GPS
- weather station
- additional thermocouples for exhaust gas temperature measurement

Figure1; PEMS main unit (SEMTECH DS) installed in a HD vehicle and PEMS EFM II attached to the exhaust.



Signals and requirements should be primarily taken from this report: GUIDE FOR THE PREPARATION AND THE EXECUTION OF EMISSIONS ROAD TESTS ON HEAVY-DUTY VEHICLES.

Exhaust gas

	Method 1	Method 2	Add TNO	Mandatory?
HC concentration	PEMS			Y
CO concentration	PEMS			Y
CO2 concentration	PEMS			Y
NOx concentration	PEMS			Y
PM mass	partial/mini dilution + gravimetric		-	
PM soot	AVL MSS		-	
PM other			-	
Exhaust Mass Flow	EFM	1.second flow sensor 2. fuel + intake air flow 3.fuel or airflow sensor + calculated A/F ratio		Y
Exhaust back pressure	sensor		maybe in case of DPF	
Exhaust temperature	sensor			Y
Exhaust temperature engine out			Mandatory TNO	

Y;Yes, N; No, P; Preffered

Engine

	Method 1	Method 2	Add TNO	Mandatory?
Engine speed	ECM			Y
Engine torque	ECM			Y
Boost pressure	ECM			
Oil pressure	ECM			
Coolant temperature	ECM		P	
Intake temperature	ECM		P	
Intake airflow rate	sensor			
Fuel rate	ECM			Y
Fuel temperature	ECM			
Fault status	ECM			

Y;Yes, N; No, P; Preferred

Vehicle parameters

	Method 1	Method 2	Add TNO	Mandatory?
Vehicle speed, mandatory	GPS			Y
Vehicle location x, y, z, mandatory	GPS			Y
Acceleration	GPS			
Travelled distance	GPS			
Elevation	GPS		only abroad	
Gen current	Current clamp		P	
Bat current	Current clamp		P	
Traffic	VidCam		P	

Y;Yes, N; No, P; Preferred

Ambient

	Method 1	Method 2	Add TNO	Mandatory?
Temperature	sensor	ECM		Y
Pressure	sensor	ECM		Y
Humidity	sensor			Y

Y;Yes, N; No, P; Preferred

C.2 Proposed Testing Programme; program of activities

A Preparation

- Obtain engine/vehicle specific data; TA documents, LUG curve, RDW vehicle registration
- Vehicle check
- Preparation of vehicle
- Installation of PEMS
- Installation of EFM, CAN, weather station, labtop, aux signals,
- Installation of Power Supply Unit (battery, Gen-set and converter)
- Add load
- PEMS audit/check; self check, PEMS calibration; span, zero, see PEMS guide and Semtech manual (make check and audit list)
- During tests; checks (audits zero, span if required, see PEMS guide and Semtech manual)

B Testing

- Tests on the road; reference trip, representative trip and special tests and conditions
- Calibration during tests (see PEMS guide and Semtech manual)
- Check of the results (quality and completeness, see also PEMS guide and Semtech manual)

C De-installation of PEMS

Proposed Testing Programme; test trips

- Representative trip[1]; for EU goal but also for representative driving cycles and emission factors
- Standard Reference Test Trip[2]; A predefined standard trip for all vehicles, including; urban, rural, highway; with all relevant traffic situations, GPS to locate traffic situations, including cold start.
- Other specific conditions for all vehicles, e.g. for modelling, to be integrated in the standard test trip. Coast down test in two directions
- Effect of auxiliaries.
- Options;
  - 2 times the same trip; for pre and post cat NOx or mount 2nd NOx analyzer, for modelling SCR efficiency
  - additional cold trip (winter)
  - additional load situations (empty, half, full)
  - no Adblue, water diluted adblue

Ad 1; Representative trip

In the PEMS Pilot Programme Project Plan it is required to drive the trip which is representative for the vehicles application. For this purpose it is an option to follow a vehicle during real operation (bus, long haul, distribution) or to follow and record the trip and than test emissions over the recorded trip.
This eventually also results in real world driving database with driving data of different HD applications, which can be used for emission modelling.

Ad 2; Standard Reference Test Trip

In general it is useful to develop a Standard Test Trip which can serve as reference for all vehicles. Such a trip could contain all driving conditions (e.g. traffic situations, engine load conditions) required for emission modelling and of interest for evaluating the real world performance of a HD vehicle.

To be divided in two parts;

1. a standard test route with traffic situations and
2. a part for special tests.

Part 1

Trip in vicinity of the emission laboratory PTC; PTC Helmond-Deurne-Liessel-A67-Geldrop-Eindhoven-N270-Helmond.

Figure 2; the standard test trip

Included in the trip are:

- Cold start, dependent on ambient temperature, but with cold engine (minimum 8 hours cooling down time required
- Urban driving
- Stop&go (if occurring)
- Idling; simulating loading – unloading (take 10 minutes) pick a suitable parking place gas station half way. Time for PEMS check (maybe no audit required)
- Rural driving; 60, 80
- Highway driving
- Steady speeds; 50, 70, 80 (N270 direction Helmond)
- Cooling down (engine off) at PTC

Part 2

- time for lunch and check up, calibrations
- engine start 60 minutes after part 1 for restart emission
- acceleration 50, 100%
- coast down
- soak 5-10-15 minutes + restart
- auxiliaries (switch aux on/off for effect, note time, or put data marker)
- arrival at PTC
- cooling down; record temperatures

The recorded trips are also very useful for developing driving/load cycles.

D Abbreviations and definitions

Definitions: EU legislation

EURO 0
An unofficial but popular indication, used in this report to indicate engines that were certified before EURO 1 came into force. In practice it concerns engines certified under 88/77/EEC.

EURO I
Usual indication of the set of limit values mentioned under A in Directive 91/542/EEC, or Reg. 49-02 respectively.

EURO II
Usual indication of the set of limit values mentioned under B in Directive 91/542/EEC, or Reg. 49-02 respectively.

EURO III
Usual indication of the set of limit values mentioned under A in Directive 1999/96/EC.

EURO IV
Usual indication of the set of limit values mentioned under B1 in Directive 1999/96/EC.

EURO V
Usual indication of the set of limit values mentioned under B2 in Directive 1999/96/EC as latest amended by 2005/78/EC.

EEV
Enhanced Environmentally friendly Vehicles. This is a class of extra clean vehicles, indicated in the set of standards under C in Directive 1999/96/EC.

CoP limit
CoP stands for Conformity of Production. The CoP limit is the maximum permissible emission for (new) engines from the production line, when tested in a CoP procedure.

SELA-scheme
A fiscal incentive scheme for "*S*chone *E*n *L*awaai *A*rme voertuigen" (clean and low-noise vehicles), i.e. vehicles that comply with more stringent limits than those that are applicable legally. The scheme ran from 1990 to 1993.

ISC, In Service Conformity

IUC, In-Use Compliance
As used in US federal legislation concerning gaseous and PM emissions

OCE, Off Cycle Emissions
The Working Party on Pollution and Energy (GRPE) is the subsidiary body of the World Forum for Harmonization of Vehicle Regulations (WP.29) that prepares regulatory proposals on pollution and energy efficiency to WP.29 in this case for Off-Cycle Emissions or emission from vehicles as they drive in the real world on the road.

Definitions: Test Methodology

13-mode test
Usual indication of the test methodology of Regulation 49 and Directive 88/77/EEC. Often referred to as ECE R49 test

DCM
Diesel Controle Methode (diesel checking method). The methodology developed by TNO to perform a 13-mode test on a chassis dynamometer. The power losses in the driveline are estimated in such a way that from a power measurement at the rollers the torque delivered by the engine can be determined.

ESC
European Steady-state Cycle following up the 13-mode test. A test with static engine loads and speeds according to Directive 1999/96/EC.

ETC
European Transient Cycle. A dynamic test, according to Directive 1999/96/EC.

PEMS
Portable Emission Measurement System; a system containing instruments to measure the regulated emissions in a vehicle driving on the road.

Regulated exhaust gas components

CO
Carbon monoxide; nuisance, toxic

HC or THC
Hydrocarbons or Total Hydrocarbons; contribute (with NO_x) to the formation of photochemical smog. Additionally, some hydrocarbons are toxic and/or carcinogenic. Measured as C_1 equivalent.

NO_x
Nitrogen oxides, consisting of NO and NO_2; causes acidification, eutrophication and plays a role in the formation of photochemical smog. NO_2 is associated with health effects. Measured as NO_2 equivalent.

PM/particulates
Particulate matter; particles in exhaust gas. Associated with a range of health effects and even with climate effects. By emission legislation defined as the material that is collected on a teflon filter when (diluted) exhaust gas is drawn through the filter during a test cycle; usually organic and elemental carbon with different kinds of organic species adsorbed, sulphur, ash, metals

Abbreviations

A/F	Air-Fuel ratio
CAN	Communication Area Network
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DF	Dilution Factor
ECU	Engine Control Unit
EFM	Exhaust Flow Meter
ESC	European Steady state Cycle
ETC	European Transient Cycle
FID	Flame Ionisation Detector analyser
FS	Full Scale
GPS	Global Positioning System
I/O	Input / Output
ISC	In Service Conformity
IUC	In Use Compliance
N_2O	Nitrous oxide
NDIR	Non-Dispersive Infrared analyser
NDUV	Non-Dispersive Ultraviolet analyser
NH_3	Ammoniac
NO	Nitric oxide gas
NO_2	Nitric dioxide gas
NO_x	Nitric oxides gases
NTE	Not To Exceed
O_2	Oxygen
OCE	Off Cycle Emissions
PEMS	Portable Emission Measurement System
PM	Particulate Matter
PFS	Partial Flow Sampling
PID	Vehicle data Parameter IDentifier
QCM	Quartz Cristal Microbalance
SAE	Society of Automotive Engineers
STP	Custom Step Cycle
TEOM	Tapered Element Oscillating Microbalance
THC	Total Hydrocarbons

Limit values – ESC and ELR tests

Row	CO g/kWh	HC g/kWh	NOx g/kWh	Particulates g/kWh	Smoke m^{-1}
A (2000)	2,1	0,66	5,0	0,10 / 0,13(1)	0,8
B1 (2005)	1,5	0,46	3,5	0,02	0,5
B2 (2008)	1,5	0,46	2,0	0,02	0,5
C (EEV)	1,5	0,25	2,0	0,02	0,15

(1) For engines having a swept volume of less than 0,75dm3 per cylinder and a rated power speed of more than 3000 min^{-1}

Limit values – ETC tests

Row	CO g/kWh	HC (NMHC) g/kWh	CH4 (1) g/kWh	NOx g/kWh	Particulates (2) g/kWh
A (2000)	5,45	0,78	1,6	5,0	0,16 / 0,21 (3)
B1 (2005)	4,0	0,55	1,1	3,5	0,03
B2 (2008)	4,0	0,55	1,1	2,0	0,03
C (EEV)	3,0	0,40	0,65	2,0	0,02

(1) For NG engines only

(2) Not applicable for gas fuelled engines at stage A and stages B1 and B2

(3) For engines having a swept volume of less than 0,75dm3 per cylinder and a rated power speed of more than 3000 min^{-1}

Overview of Euro IV and V sub stages

Popular name	Letter	Row	OBD phase I	OBD phase II	Durability and ISC	NO_X control
Euro III	A	A	-	-	-	-
Euro IV	B	B1(2005)	Y	-	Y	-
Euro IV	C	B1(2005)	Y	-	Y	Y
Euro V	D	B2(2008)	Y	-	Y	-
Euro V	E	B2(2008)	Y	-	Y	Y
Euro V	F	B2(2008)	-	Y	Y	-
Euro V	G	B2(2008)	-	Y	Y	Y
EEV	H	C	Y	-	Y	-
EEV	I	C	Y	-	Y	Y
EEV	J	C	-	Y	Y	-
EEV	K	C	-	Y	Y	Y