# $NO_x$ Emissions of Heavy-Duty Vehicles with Euro VI Certified Engines

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## Summary

In the Dutch in-service emissions testing programme, the nitrogen oxide ($NO_x$) emissions of 46 vehicles with Euro VI certified engines were measured during normal daily operation using the Smart Emission Measurement System (SEMS). To screen the in-service conformity, a number of vehicles were tested over the prescribed in-service conformity test routes using SEMS and in some cases the Portable Emission Measurement System (PEMS).

All the screened vehicles showed indicative good results over the in-service conformity routes using the pass-fail evaluation method. In daily operation however, the $NO_x$ emissions vary a lot from case to case and are often not as low as one might expect based on the EU standard. The variation in $NO_x$ emissions is largely caused by the spread in operation profiles between the vehicles. Average speeds vary and especially at low speed, low load the probability that $NO_x$ emissions increase is higher. The cause is the fact that in these conditions the $NO_x$ abatement technology that is present on Euro VI step A to C certified engines is not always fully effective.

In September 2019 the EU implements step D in Euro VI legislation. Later on it will round off Euro VI with the implementation of step E. These steps contain some changes for the road test with PEMS, which are intended to better cover the low load, low speed operation of heavy-duty vehicles as occurring in normal daily operation. It is however still recommended to add provisions in the EU regulation for testing vocational vehicles over routes that represent their normal use.

Continuation of monitoring new heavy-duty vehicle emissions will show the possible impact of the changes of step D and step E on the real world $NO_x$ emissions. For diesel engines in non-road mobile machinery (NRMM) in principle the same issue exists. It is therefore recommended to intensify monitoring of $NO_x$ emissions of NRMM in normal use.

## Introduction

In cities and near roads with dense traffic, concentrations of $NO_2$ in the air still exceed the EU limits. Locally, traffic is the main source but remote sources contribute to background concentrations as well. From traffic, vehicles with a diesel engine emit the most $NO_x$ and $NO_2$ which means that for areas with a high density of vehicles with a diesel engine, the contribution of traffic is high. Reduction of the tail pipe $NO_x$ emissions from these vehicles is desirable from an air quality point of view. In the last two decades, EU emissions regulations tried to command a reduction of the $NO_x$ emissions from vehicles with a diesel engine, but only managed to establish substantial reductions as of the introduction of Euro VI (Vermeulen et al., 2016). The substantial reduction of the $NO_x$ emissions from diesel engines is mainly achieved by the application of an exhaust gas aftertreatment system that uses Selective Catalytic Reduction (SCR). The SCR system is often complemented by Exhaust Gas Recirculation that reduces the $NO_x$ load entering the SCR.

For vehicles with the first generation of Euro VI engines it was reported (Vermeulen et al., 2016) that $NO_x$ emissions of vehicles with Euro VI certified engines have on average decreased substantially compared to the $NO_x$ emissions of previous generations of engines. This is partly due to a more stringent limit for the $NO_x$ emissions, but also due the introduction of an emission test that has to be conducted on the public road. As of Euro VI (31 December 2013), the test with a Portable Emission Measurement System (PEMS) became a mandatory part of the EU type approval process in the form of an in-service conformity test.

Studies by (Vermeulen et al., 2016) and (Söderena, P., Nylund, N., 2018) showed that for certain heavy-duty vehicle applications despite the more stringent requirements $NO_x$ emissions may be higher than expected, based on the limits for the engine test and the in-service conformity (ISC) test on the public road. In (Vermeulen, Ligterink, 2018) it was demonstrated that substantial parts of normal driving, such as driving at a low engine load and driving in the city, may fall outside of the boundaries of the ISC test on the public road. Together, this leads to the situation that $NO_x$ emissions levels of vehicles with a Euro VI certified engine still depend on actual driving conditions and exceed the Euro VI limit values. Therefore, within the Dutch in-service emissions testing programme, TNO is conducting for the Ministry of Infrastructure and Water management, it was decided to test a number of different representative HDV vehicles of different types of applications in normal daily operation, to determine actual $NO_x$ emissions levels.

The general objectives of the Dutch in-service emissions testing programme are to:

- Determine the emission factors for heavy commercial vehicles
- Determine trends over the different EU standards and steps:
  - Are the vehicles getting sufficiently cleaner each generation/step <u>in the real world</u>?
  - Use the data and insights in Brussels in discussions about the improvement of the test procedures
- Screen the in-service conformity
- Assess new/alternative technologies
- Provide information to stakeholders, to help make purchase decisions for cleaner and more fuel efficient transport

This paper presents $NO_x$ emissions data that was gathered throughout the programme in the period 2015 to 2019 for 46 vehicles with Euro VI certified engines and gives an overview of the data, with a focus on:

- the determination of $NO_x$ emissions of heavy-duty vehicles with Euro VI-step A and a few C (as of Sept. 2016) certified engines, under a range of normal representative driving conditions which are considered normal use in the Netherlands,

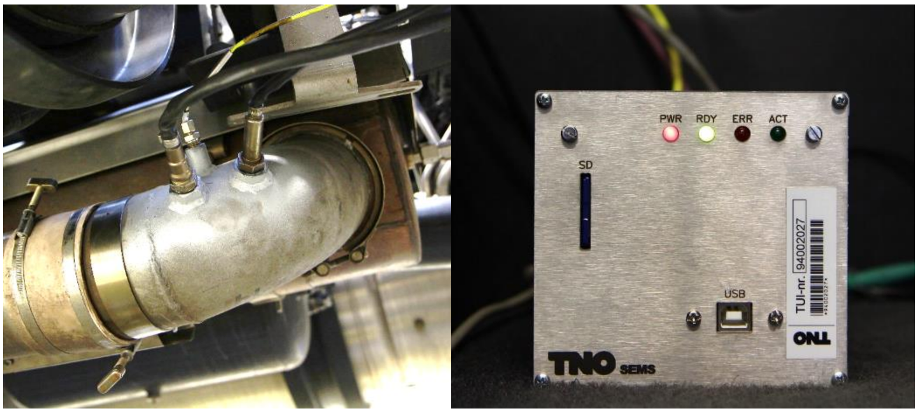
- the limited coverage of normal operation in the Netherlands by the EU PEMS test for in-service conformity

## Method: Real-world emission monitoring using SEMS and PEMS

The emissions measurement programme aimed at determining the real-world $NO_x$ emission levels of heavy-duty vehicles. The Smart Emissions Measurement System (SEMS), a sensor-based system developed by TNO (Heijne et al. 2016), was used to measure and analyse the tail-pipe $NO_x$ emissions and a range of vehicle/engine parameters to be able to characterize the typical operation of the vehicles. In this way, for the group of vehicles, weeks up to months of data was collected per vehicle.

The SEMS uses an automotive $NO_x$ sensor, GPS and a data-acquisition system to record the sensor data and CAN data from the vehicle and engine at a sample rate of 1Hz. The system can operate autonomously and wakes up at ignition/key-on of the vehicle. The system can be stowed away so that normal operation is not hindered by the measurement. The recorded data is sent hourly to a central data server.

*Figure 1: SEMS. Left, calibrated $NO_x$-$O_2$ sensor, $NH_3$ sensor and temperature sensor mounted in the tail-pipe. Right, autonomously running data recording unit with hourly data transmission to a central server via GPRS.*




The raw data on the central server is post-processed automatically to filter and check the data. Sensor output is corrected using sensor specific calibration values. Mass-emissions and instantaneous engine power are calculated combining sensor data and CAN data such as manifold-air flow, fuel rate, engine torque, and sensor $O_2$ concentration where possible. For the vehicles for which no sufficient engine data were available to calculate the work specific emissions, an estimation of the average brake specific fuel consumption and $CO_2$ emission of the engine was used to estimate the vehicle's emissions in g/kWh.

For more accurate technology assessment and in-service conformity checking in some occasions also a Portable Emissions Measurement System (PEMS) has been used to measure the $NO_x$ emissions on the public road. A limitation is that the tests re bound to well-defined test routes and represent only a few hours of vehicle operation while a merit is the more accurate measurement and the fact that it is the formally prescribed instrument for in-service conformity testing.

*In-service conformity screening*

The Dutch in-service emissions testing programme aims to screen the in-service conformity. This means that indicative tests are performed to determine whether or not there is an increased probability that an Euro VI certified engine in a vehicle fails the formal in-service conformity test. The process contains a number of steps:

1. *SEMS screening test*: When SEMS is mounted, the vehicle is also checked (MI and display error codes) and the owner is asked to provide information about the history of the vehicle. The SEMS data from the vehicle in daily operation is used to determine the SEMS Factor (Heijne, 2016) applying the pass-fail evaluation rules of a formal PEMS test, using the SEMS data instead. In the case the SEMS Factor is higher than 1.5 proceed to 2, otherwise proceed to 4.

2. *SEMS screening ISC route*: Perform additional checks on the vehicle. Read OBD for error codes, check Malfunction Indicator and display for possible error signs. Run an in-service conformity test route using the SEMS that is already mounted on the vehicle. The SEMS Factor is calculated for this trip applying the pass-fail evaluation rules of a formal PEMS test. In the case the SEMS Factor is higher than 1.5 the result is communicated to the national Type Approval Authority. If the SEMS Factor is lower than 1.5: proceed to 3 or 4.

3. *PEMS ISC test:* Optionally, it can be decided to perform an additional test according the formal test requirements with PEMS.

4. Archive test data in the database. Report overall results in an annual report. Send a summary of the result of each vehicle to the national TAA.

After each step of the process the OEM is invited to discuss the results.

*Vehicle selection: heavy-duty vehicles with Euro VI certified engines*

Since the introduction of Euro VI on the market in 2013 the focus of the Dutch programme changed to testing the new generation of engines and emissions abatement in heavy-duty vehicles. Each year a ranking for each vehicle class (city bus, medium truck, heavy truck, RCV) was made, based on the number of registrations of each Euro VI engine type/family. This has led to a test sample containing 46 individual heavy-duty vehicles, most with a diesel engine. The second group were 'specialties'. Vehicles in this group were selected not only by their engine type/family, but also by the purpose of the vehicle. Waste collection trucks and city buses were selected for this purpose. For an assessment of environmental technology, vehicles on alternative fuels have been tested as well. See the table for the categories of vehicles that have been tested and the tests performed with those vehicles. A limitation of the dataset is that the vehicle mileages, as read from the odometers at the start of the tests, are still relatively low. Odometer readings range from 20.000 km to about 400.000 km for one N3 class tractor in a single case while for instance for the latter lifetime mileage expectance would be 1.2 to 1.5 million kilometres. It means that there are no old vehicles in the dataset and possible ageing effects are accounted for given the relatively fresh fleet of test vehicles.

*Table 1: overview of the test sample with vehicle categories tested, types of vehicles tests and number of vehicles of each type tested.*

| | | **PEMS** | **SEMS** |
|---|---|---|---|
| **Tractor (semi) trailer** | CI*(Diesel) N3 | 6 | 8 |
| | SI** (LNG) N3 | 2 | |
| | HDDF*** LNG -diesel N3,1A | 1 | 1 |
| **Rigid** | CI (Diesel) N2 | 1 | 4 |
| | CI (Diesel) N3 | | 4 |
| **Refuse Collection Vehicle** | CI (Diesel) N3 | | 8 |
| | SI (LNG) N3 | | 1 |
| | SI (CNG) N3 | | 1 |
| **Buses** | CI (Diesel) 12m | 2 | 2 |
| | CI (Diesel) 18m | | 3 |
| **Tipper** | CI (Diesel) N3 | | 1 |

*CI: Compression Ignition engine. **SI: Spark Ignition engine. ***HDDF: Heavy-Duty Dual Fuel engine.

## Results: in-service conformity screening

The majority of vehicles has been put to a screening test with SEMS and/or PEMS. Result of this is for the tested vehicles that in 5 cases the initial SEMS screening test lead to false positives. I.e. when eventually the applicable SEMS ISC route was driven the SEMS screening Factor was lower than 1.5. In the case of one PEMS test, the test proved not fully compliant with the formal ISC requirements. For one vehicle, an N3 class, diesel Refuse Collection Vehicles (RCV) white deposits were found in the tail-pipe rendering the SEMS measurement invalid. The white deposits gave cause for further investigation of the vehicle by the OEMS which is not yet finished. Four vehicles are currently being tested with SEMS.

*Table 2: overview of ISC screening test results.*

| EU vehicle category, engine | | PEMS Test |
|---|---|---|
| **N3, CI** | | CF<1.5 (6) |
| **N2, CI** | | CF>1.5 (1, trip not compliant) |
| **N3, SI (LNG)** | | CF>1.5 (2) |
| **N3 HDDF (LNG -diesel)** | | CF<1.5 (1) |
| **M3, CI** | | CF<1.5 (2) |
| | **SEMS screening test** | **SEMS screening ISC route** |
| **N3, CI** | CF<1.5 (6) | |
| | CF>1.5 (3) | CF<1.5 (3) |
| | CF=? (1) SCR deposits | Investigation running (1) |
| | Test running (4) | |
| **N2, CI** | CF<1.5 (4) | |
| | CF>1.5 (2) | CF <1.5 (2) |
| **M3, CI** | CF<1.5 (4) | |
| | CF>1.5 (1) | CF<1.5 (1) |

## Results: Real world $NO_x$ emissions levels for the different vehicle categories

Total average $NO_x$ emissions were determined for all vehicles. There is a large spread in average speed and $NO_x$ emissions between all vehicles.

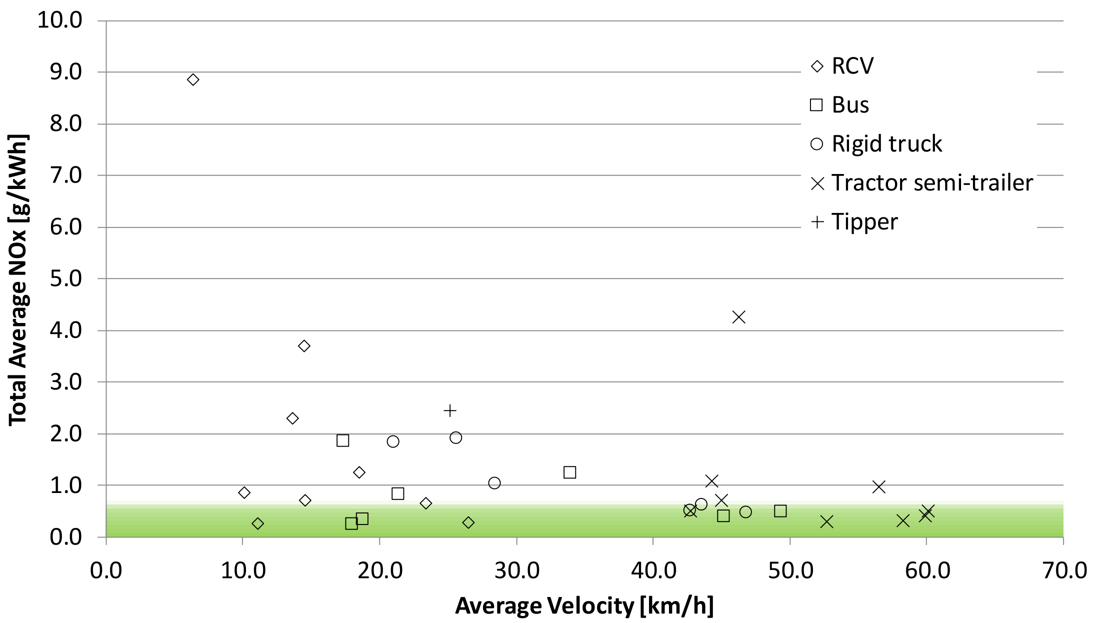



*Figure 2: total average NOx emissions versus average speed for all vehicles tested with SEMS in normal daily operation. The upper side of the green area represent a NOx emissions level of 0.69 g/kWh, which is the limit of the conformity factor of 1.5 expressed in gNOx/kWh (1.5x0.46=0.69 g/kWh) for the formal ISC test.*

*Refuse collection vehicles* have the lowest average speeds. from 6 to about 26 km/h and the largest spread in $NO_x$ emissions and this results in a large spread of average $NO_x$ emissions, from 0.3 to 9 g/kWh. RCV operation is characterized by stops for refuse collection and stop times depend on type of refuse collected (small containers, large containers, garbage bags, coarse refuse) and driving speeds depend on the area that is serviced. In cities speeds are lower as opposed to rural areas and small villages. The highest $NO_x$ emission was measured in a case of coarse refuse collection with long stops for manual loading of the refuse and short driving intervals. Measurements for this vehicle were executed in winter time and the emission abatement concept was 'SCR only', meaning there is no additional Exhaust Gas Recirculation to reduce diesel engine $NO_x$ emissions. For another vehicle, $NO_x$ emission were low despite a low average speed. This vehicle used a high amount of power from the power take off to lift large under floor containers. Another vehicle has a throttle valve which can control diesel engine lambda (air to fuel ratio) so that exhaust temperatures remain higher at low speeds and $NO_x$ remains low, even at low speeds.

*Buses* have higher average speeds, from 17 to 49 km/h. However, from the dataset over individual city bus lines average speeds are noted as low as 13 km/h. The higher speeds are for buses that service rural areas and villages from a larger city. Usually, these buses stop at less bus stops in a city and often exit and re-enter the city centre straight away. This means that average driving speeds will be higher in urban areas and on average higher because driving contains rural roads and sometimes a motorway. Average $NO_x$ emissions remain below 2 g/kWh.

Average speeds of *rigid trucks* spread a lot as well but are not as low as for buses and refuse collection vehicles. Rigid trucks include the lighter versions around 10t that are used for city distribution (delivery of goods and parcels) and typically show the lowest average speeds. In those cases NOx emissions are generally the highest, on average up to 2 g/kWh down to 0.5 g/kWh for the operations with higher average speeds. Some of the trucks distribute through the country and drive a lot of motorway to enter a city and deliver goods throughout a city which brings average speed downward.

The *long haulage trucks or tractor semi-trailers* have the highest average speeds up to about 60 km/h. Still not all these vehicles run mainly motorways. Three of the vehicles are used to service supermarkets from distribution centres and clothing shops. These vehicles tend to have a lot of starts and semi-warm operation because the vehicle is moved around at distribution centres and near shows. One vehicle distributes flowers to France but despite a lot of motorway time also spends a lot of time (about 30% of total operational time) in northern French cities to distribute flowers to the shops. $NO_x$ emissions for all tested vehicles vary from as low as 0.3 g/kWh to about 1 g/kWh. A high $NO_x$ emission was measured for one vehicle of 4.3 g/kWh. The vehicle hardly uses reagent (AdBlue) the consumable which is needed for an SCR to work.

The 4x8 *tipper* hauls sand to construction sites. It drives from a depot to the site where work consists of a lot of idling, low speed dumping and manoeuvring at he site. Hence, the relatively low average speed. Also the operation has periods of high engine load when the vehicle is fully loaded with sand versus low engine loads for running empty. The prolonged periods at the construction sites and low payload afterwards together lead to average NOx emissions being somewhat higher and around 2.5 g/kWh on average.

When the data of all vehicles is divided over speed bins for low, medium and high speed it becomes apparent that at low speeds $NO_x$ emissions for most of the vehicles are higher.

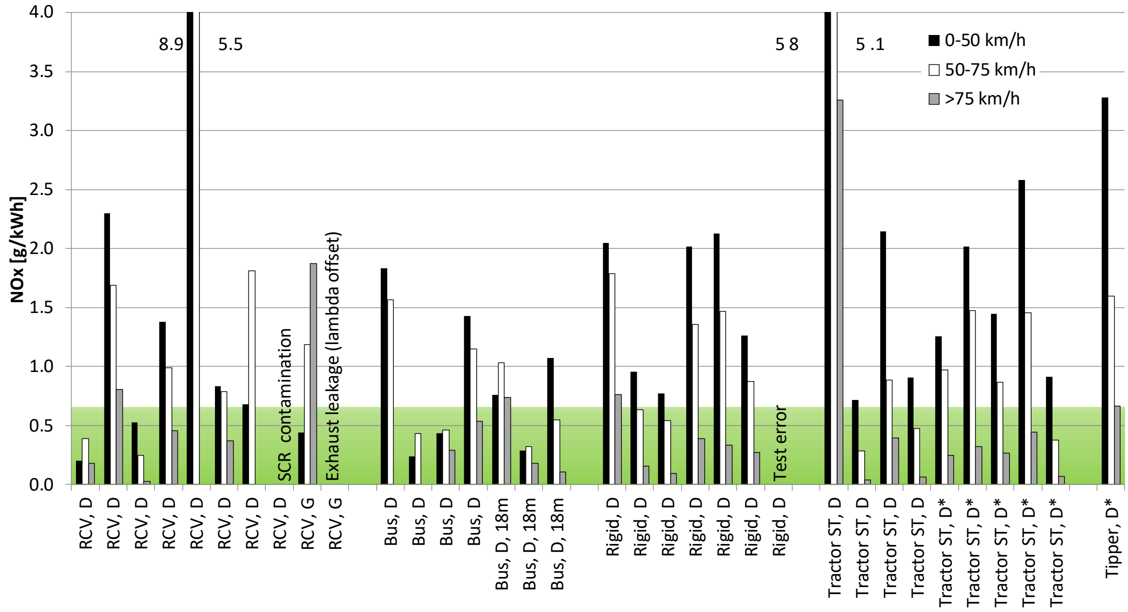



*Figure 3: overview of real world $NO_x$ emissions as measured with SEMS during daily operation for a number of different vehicle types, all with Euro VI certified engines. Three speed ranges are distinguished. * represents Euro VI step C, all others Euro VI step A. D=Diesel, G=Gaz (CNG or LNG). The upper side of the green area represent a NOx emissions level of 0.69 g/kWh, which is the limit of the conformity factor of 1.5 expressed in gNOx/kWh (1.5x0.46=0.69 g/kWh) for the formal ISC test.*

For a certain share of total emissions this is caused by cold engine operation. Warming up of a heavy duty engine is most often done by idling or running at low speeds. Elevated emissions produced during this period, because emission abatement is not yet active, contribute to the higher emissions. Cold engine operation (Coolant temperature is below 70° C) is for most vehicles 3 to 10% of the total time, but individual cases show cold operation up to 32% when vehicles idle a lot. Cold emissions shares in total emissions depend a lot on how much is emitted when the engine is warm. For example emissions after cold starts can contribute 30% to total emissions when the overall emissions are low (0.5 g/kWh). A large share of the higher $NO_x$ emissions at low speeds is caused during warm engine operation when SCR temperatures drop below working temperatures.

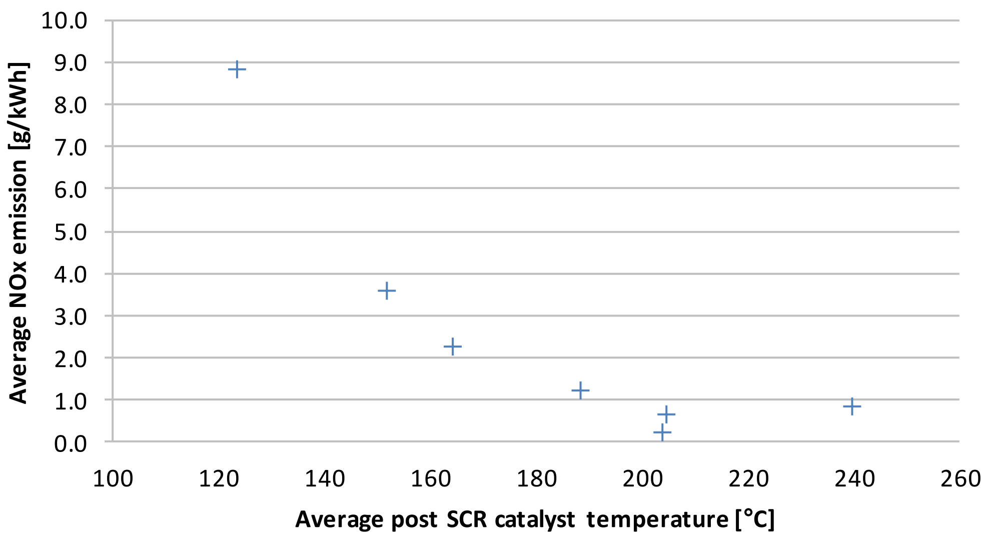



*Figure 3: relation between total average $NO_x$ emissions and average post SCR exhaust gas temperature for the refuse collection vehicles.*

## Euro VI and PEMS test for ISC: limited coverage of normal operation

For the regulation of $NO_x$ emissions of engines of heavy-duty vehicles a number of measures are implemented in the type approval framework. The basis is a type approval emissions test of the engine that demonstrates the emission performance with regard to the regulated gaseous pollutant emissions of the given engine type. This is amongst others complemented by additional requirements to check the conformity of production, on-board diagnostics (functionality of emissions critical components), the $NO_x$ measures (e.g. AdBlue consumption) and in-service conformity. The latter is an important test that as of Euro VI (31 December 2013) needs to be conducted with the engine in a representative vehicle, on the public road. Engines have to comply to a so called maximum conformity factor standard of 1.5 that relates to the emissions limit of the engine test, for $NO_x$ 1.5 x 0.46 g/kW = 0.69 g/kWh. Vehicles need to be in-service, comply over the useful life that depends on the legislative category (e.g. 700.00km for N3, GVW>12t trucks) and have no malfunctions. Malfunctions are to be detected by on-board diagnostics, with a threshold limit for $NO_x$ and the $NO_x$ measures. In certain cases drivers/owners are forced to make necessary repairs because a torque inducement may render normal operation of the vehicle impossible until the repair is done. The whole package of test and requirements should guarantee sustainably low emissions over the useful life of a heavy-duty vehicle. Previous tests on heavy-duty vehicles reported in (Vermeulen et al., 2016) showed higher $NO_x$ emissions than expected based on in-service conformity test limits which indicate a limited coverage of normal operations by the in-service conformity PEMS test. This has led to the decision for the Dutch test programme to extend testing, to vehicle categories that operate in cities (RCV, buses, distribution trucks).

*Table 3: Overview of most important $NO_x$ requirements in EC Regulation numbers 595/2009, 582/2011 and subsequent amendments*

| | |
|---|---|
| **NOx limit WHSC/WHTC engine test** | 400 / 460 mg/kWh |
| **PEMS test for OCE/TA and ISC** | Yes |
| **PEMS Conformity Factor limit** | 1.5 (1.5 x 0.46 g/kWh) |
| **PEMS data exclusions** | 10% highest MAW, power threshold, cold start (see below) |

| **Euro VI step** | NOx OBD threshold limiet [g/kWh] | Additional OBD monitors | PEMS Power threshold | PEMS Cold start | PEMS PN | PEMS urban MAW | PEMS payload | Implementation date all vehicles |
|---|---|---|---|---|---|---|---|---|
| **A** | 1.5 | N | 20 | N | N | n.b. | 50-60% | 31-12-2013 |
| **B** | 1.5 | N | 20 | N | N | n.b. | 50-60% | 01-09-2015 |
| **C** | 1.2 | Y | 20 | N | N | n.b. | 50-60% | 31-12-2016 |
| **D** | 1.2 | Y | 10 | N | N | Y | 10-100% | 01-09-2019 |
| **E** | 1.2 | Y | 10 | Y | Y | Y | 10-100% | t.b.d |

For the first generations of Euro VI engines, step A to C, low load and low speed operations fall outside the boundaries of the PEMS test for in-service conformity[1]. Low power operation and high emissions events are excluded from the test evaluation (Vermeulen et al., 2018). Also for the heavy category of vehicles >12t (N3) urban operation is not, or partly in the test evaluation and the mentioned exclusions may delete the remainder of urban operation from the test evaluation. Up to step C, only medium payloads are prescribed for the test, while in normal use payloads from 0 to 100% are common. Vocational vehicles are tested according their GVW category over mostly either an N2 distribution trip (GVW 3.5-12t) or an N3 long haulage trip (GVW>12t). Refuse collection vehicles are often build on an N3 chassis and as such the engine is only tested in a long haul truck with the majority of the test being motorway operation while urban driving and low loads are being excluded. For city buses (M3, class 1) there is already a dedicated bus route, the M3 route which contains 70% of urban driving. Nevertheless, low loads had still to be excluded, according evaluation rules up to a maximum of 50% of the test windows (Moving Averaging Windows). High emissions events (10% of the test windows (MAW)) are also still excluded from the PEMS test.

The observed higher and varying $NO_x$ emissions, especially at low load low speed operation, has been debated in the Brussels EU PEMS expert working group in the recent years. This has led to improved test procedure and new more stringent requirements as of step D (Implementation date 'All vehicles': 1 September 2019):

- Lower power threshold from 20 to 10%.
- Extension of payload range from 50-60% to 10-100%.
- Inclusion of mandatory urban moving averaging window, mainly relevant for N3 and possibly also for N2.
- Extension of the urban part of the N3 route from 20 to 30% of the test time. This is excluding the cold period.
- Better definitions for the trip sub parts and longer allowed total test time.

[1] EC regulation nr. 582/2011

Further improvements are expected for step E (implementation date is not fixed yet) with inclusion of the cold start, a particle number test and additional requirements auxiliary emission strategies (AES).

Monitoring the $NO_x$ emissions by means of real world emissions testing would reveal the impact of these changes on the $NO_x$ emissions levels for normal daily operation of heavy duty vehicles.

## Conclusions

In the Netherlands in-service emissions testing programme for heavy-duty vehicles a number of vehicles with Euro VI certified engines of different categories were tested. Tail-pipe emissions levels of vehicles with Euro VI engines were examined using a Smart Emissions Measurement System to determine the level of $NO_x$ emissions when operated on their normal daily routes, i.e. under real-world conditions. A selected group of vehicles was tested with PEMS over specified test routes of a few hours long. When high $NO_x$ emissions were observed, vehicles were also tested over specified in-service conformity routes to get an indication of the $NO_x$ emission conformity of the vehicle in-service. The vehicles were selected based on ranking of registrations of engine type and are a good representation of the Dutch fleet of heavy-duty vehicles with a Euro VI certified engine.

When a formal in-service conformity route was driven, all vehicles had an indicative in-service conformity factor below the limit of 1.5.

For the Euro VI certified diesel engines the overall average $NO_x$ emissions levels in normal daily operation still vary a lot from case to case, from about 0.3 g/kWh to 4 g/kWh and 9 g/kWh in a special case. Largest variations and high $NO_x$ emissions were observed for the cases with higher shares of low speed and low engine load operations for instance at urban driving combined with a lot of idling, where $NO_x$ emissions tend to be clearly higher. Typical examples are city refuse collection, city bus lines, city distribution of goods, also by long haulage trucks and in one case construction services. For those cases, in local driving situations, but also for average operation, the limit value[2] that is set for the formal EU type in-service conformity test, a specific test to be conducted on the public road, are regularly exceeded.

At motorway speeds $NO_x$ emissions are consistently low, typically around 0.1-0.5 g/kWh.

The increase of $NO_x$ emissions at low average speeds for diesel vehicles is related to the way the emission abatement technology with selective catalytic reduction (SCR) works. The catalyst of this type of emission control system needs to be warm to effectively reduce the $NO_x$ emissions of the diesel engine. At low engine loads (power), the catalyst may cool down due to the cooler exhaust gas of the diesel engines at those conditions. Actual $NO_x$ emission levels thus depend on if and how much during a trip the SCR catalyst cools down due to low load operation.

The observed good results for $NO_x$ emissions over indicative in-service conformity screening tests on the one hand and the large spread of $NO_x$ emissions for the same vehicles in normal daily operation in the Netherlands on the other hand, show that not all representative and normal operations are well-covered by the EU emissions legislation. This accounts for the Euro VI certified engines of step A to C.

For Euro VI step D additional requirements are implemented that should improve the situation and especially the higher NOx emission at lower speeds and loads. The impact has to be measured once step D certified vehicle enter the market as of September 2019.

There are no provisions for testing vocational vehicles. Refuse collection vehicles for instance are tested as N3 vehicle over a long haulage test route. It is recommended to adapt the EU regulation so that engines of heavy-duty vehicles that usually operate in urban driving are always tested with sufficient urban driving and with representative driving cycles. For engines that are used in refuse collection vehicles the bus route could be used.

[2] the Conformity Factor of the EU in-service conformity test represents 1.5 times the limit value for the WHTC engine certification test (1.5 x 0.46 = 0.69 g/kWh)

Continuation of monitoring the emissions of heavy-duty vehicles during the life time of the vehicles reveals trends of these emissions and the effectiveness of EU emissions legislation in achieving sustainably low emissions over the useful life of the category of heavy-duty vehicles.

## Acknowledgements

Acknowledgments go to all transport companies which provided their vehicles for testing in the Netherlands in-service emission testing programme and The Ministry of Water management which funds the testing programme.

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