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TNO report

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Approaches for detecting high NO_x emissions of aged petrol cars during the periodic technical inspection

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Summary

Emission tests in earlier TNO studies show that a small group (6%) of petrol passenger cars, with a malfunctioning three-way catalytic converter, account for a large proportion (36%) of the total NO_x emissions of passenger cars. NO_x emissions in vehicles with a defective three-way catalytic converter can increase by a factor of 10 or more relative to well-functioning vehicles. The current tests in the Dutch periodic technical inspection (PTI) fail to effectively detect such defects in petrol vehicles. As a result, vehicles with a malfunctioning three-way catalytic converter remain in use, resulting in high NO_x emissions.

This problem will persist for the coming years because no adjustments are foreseen in the legislation that governs the PTI. In 2030, the total additional NO_x emissions from defective petrol passenger cars are estimated at 3 kton, or about 22% of the total NO_x emissions from passenger cars.

Detecting defective three-way catalytic converters in petrol cars is more difficult than detecting defective particulate filters in diesel cars. Emissions from petrol engines show large variations in normal use, so there is no simple limit to be set for properly functioning systems. The high NO_x emissions seem to be related to the regulation of the catalytic converter and the lambda sensor. The limit in the current PTI test, in which the lambda value must not exceed 1.03, is too broad to be able to detect these problems. This is confirmed by an earlier TNO study in which several vehicles with high to very high emissions did not fail the PTI test. The problem is further exacerbated by the fact that emission measurements are no longer carried out in the PTI if the European On-Board Diagnostics (OBD) procedure is successfully completed, and no emission-related faults are found. Since there are indications that OBD systems of cars are (partially) switched off after 100,000 kilometres, it is questionable whether this is a reliable component for the PTI checks in older vehicles.

Some new tests to detect malfunctioning three-way catalytic converters are discussed in this report. One possibility is to tighten the limit of the lambda value of the PTI emission test. An additional test of the mounted lambda sensor can also detect problems related to the control of the three-way catalytic converter.
Both options require minimal development. An additional cold start test during the PTI is also an option for detecting defective three-way catalytic converters.
A well-functioning three-way catalytic converter significantly reduces emissions within 20 seconds. For a targeted cold start test in the PTI, however, further developments are necessary.

In order to detect major defects in older vehicles, a one-off comprehensive inspection of a vehicle with more than 160,000 km may be an effective option.
This mileage threshold is related to the European durability requirements.
This is the period during which the manufacturer must ensure that a well-maintained vehicle in its original state continues to function properly. Market surveillance of the functioning of the OBD and the quality of replacement parts can also help.

In order to be able to use statistical data to detect defects, PTI and other test results will have to be collected. PTI and other test results should be collected in a centralised database. Demonstrating the feasibility and exact savings potential of these solutions requires a follow-up study.

Contents

1 Introduction

Emission tests in earlier TNO studies show that a small group (6%) of petrol vehicles, with a malfunctioning three-way catalytic converter, account for a large proportion (36%) of the total NO_x emissions of passenger cars[1,2]. In a letter to the Dutch lower chamber of parliament the minister of infrastructure and water management stated the following: "In order to determine which approach is effective in detecting and tackling this problem, further research is required into what a possible test could look like and at what cost and when it could be carried out. I will have this mapped out in the near future and will then inform your House of the results"[3]. As a result of this, TNO was requested to investigate the possibilities of tackling the elevated NO_x emissions of petrol passenger cars. TNO was specifically asked to investigate possible practical solutions for addressing this group of vehicles.

Correctly functioning emission after-treatment technology on modern vehicles reduces the emission of harmful substances by 90% up to more than 99%. Defects in these emission control systems therefore can lead to substantial increases in emissions. As a result, a small proportion (1% to 10%) of vehicles with defects can lead to a doubling of total NO_x emissions. Emission reduction technologies include: the three-way catalytic converter equipped to petrol cars, as introduced from 1992, the particulate filter on diesel cars as introduced from 2009 and the SCR catalytic converter on diesel cars from 2018. The proper functioning of these systems is essential for low emissions of harmful pollutants.

The Dutch vehicle regulation ("*Regeling Voertuigen*") stipulates that petrol passenger cars from 1992 and petrol commercial vehicles from 1994, which are equipped with an emission control system consisting of a catalytic converter and a lambda sensor, must function correctly. Its proper functioning is assessed by the carbon monoxide content of the exhaust gases and by an air-fuel ratio calculated on the basis of the composition of the exhaust gases. For petrol passenger cars with a permitted mass not exceeding 3,500 kg that were put into service after 31 December 2005, the On-Board Control system is read out instead of an emission test on the exhaust.[4]

In practice, however, it appears to be difficult to rely on this approach. None of the petrol vehicles found in the TNO study with high to very high NO_x emissions were rejected according to the requirements of the *Regeling Voertuigen*. Even a major service at a garage did not lead to a reduction in emissions in most cases. Only specific repairs, at the request of TNO, proved to be partially effective. The tests in the periodic technical inspection (PTI), and the alternative in the form of checking the European On-Board Diagnostic (OBD) system, were not effective. In the context of the development of new European emission legislation, it has also been concluded that the OBD in Europe serves only serves its purpose, of the prevention and repair of emission-increasing defects, to a limited extent.

[1] On road emissions of 38 petrol vehicles with high mileages, TNO rapport 2020 R11883.
[2] Emissions of twelve petrol vehicles with high mileages, TNO rapport 2018 R11114.
[3] Tweede Kamer, Kamerstukken II 2020/2021, 31 209, nr. 227.
[4] Regeling voertuigen: https://wetten.overheid.nl/BWBR0025798/2022-01-01

2 Environmental impact of undetected defects

The effects of the ageing of petrol vehicles and the defects that accompany it led to a substantial increase in NO_x emissions. Most petrol cars have typical NO_x emissions of 100 mg/km or less, depending on their use and age. Due to defects, this can increase to 1000 mg/km or more. Several vehicles have been measured with an increase of 200 mg/km to 400 mg/km. It is expected that these increases will mainly occur after 150,000 kilometres driven at an age of 10 years or older. This concerns over a third of all passenger cars in the Netherlands.

TNO's research results are also confirmed by studies using remote sensing measurements. The increases in average emissions from petrol cars as they age are typically a factor of two to four[5]. A study in Flanders shows that for petrol cars and other relatively clean vehicles, a substantial part of total emissions comes from a small group with much higher than average emissions for these vehicles[6].

2.1 Elevated NO_x emissions from petrol cars until 2030 and beyond

Estimates of future emissions[7] indicate that this problem will persist and will probably become relatively more pronounced as new vehicles become cleaner, vehicles stay on the road longer and vehicles drive more kilometres over their lifespan. Whereas 30 years ago a car was ready for scrapping after 10 years, today cars last almost 20 years. In the past year, the effects of ageing of petrol cars as observed for Euro-3, Euro-4, and Euro-5 have also been applied to determine the emission factors of Euro-6. As a result, for 2030 the emission factors of Euro-6 petrol cars have been adjusted from 43 mg/km in the city, 20 mg/km on rural roads and 11 mg/km on motorways, to 76, 56 and 44 mg/km respectively in 2021. This is over 1 kton of additional NO_x emissions from the newest generation of cars in addition to the large contribution of around 2 kton of NO_x from older petrol cars (Euro-5 and older). It is estimated that there will probably still be several million of such vehicles in circulation in 2030. The effect of defects in Euro-5 vehicles and older has been included in the Dutch national emission reports since 2019[8].
The additional NO_x emissions from undetected defects in petrol cars are expected to total about 3 kton in 2030. To put this in perspective, the total NO_x emissions from mobility in 2030 are estimated to be 84.3 kton and the contribution of passenger cars alone is estimated at 13.7 kton. These additional emissions therefore make up a substantial proportion of the total emissions[9].

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[5] Study on the durability of European passenger car emission control systems utilizing remote sensing data, IVL rapport 2019 C 387, Sweden.
[6] Analysis of the 2019 Flemish remote sensing campaign, Vlaams Planbureau voor Omgeving, Brussel, 2020.
[7] Emissiefactoren wegverkeer: wijzigingen en uitbreidingen 2021, TNO rapport 2021 R11981.
[8] Emissiefactoren wegverkeer. Actualisatie 2019, TNO rapport 2019 R10825.
[9] Emissieramingen luchtverontreinigende stoffen. Rapportage bij de Klimaat- en Energieverkenning 2020, PBL 2020 publicatienummer 4211.

3 Vehicle requirements

A vehicle has to meet several environmental requirements when sold, but as the vehicle ages, these requirements decrease. In 2007, Euro-5/6 legislation prescribed five years and 100,000 kilometres as the useful life for which requirements apply, while passenger cars as a rule of thumb drive more than twice as many kilometres and are in use twice as long[10].

Beyond 100,000 kilometres, the manufacturer no longer has to check whether vehicles comply with the In-Service Conformity (ISC) requirements. For emission control technology, there is a further durability requirement that components must have an effective service life of 160,000 kilometres. With the new market surveillance applicable from 2020, this may be subject to some enforcement. Beyond 100,000 kilometres, the car manufacturer's responsibilities decrease and, after 160,000 kilometres, the manufacturer can no longer be held accountable for the car's environmental performance. There is also no control, by the type-approval authority, of the functioning of the on-board diagnostic system itself beyond 100,000 kilometres, although there is a requirement that the OBD continues to work throughout its service life. This means that there is limited control as to whether the systems, on which the PTI is largely based, still function at high mileages.

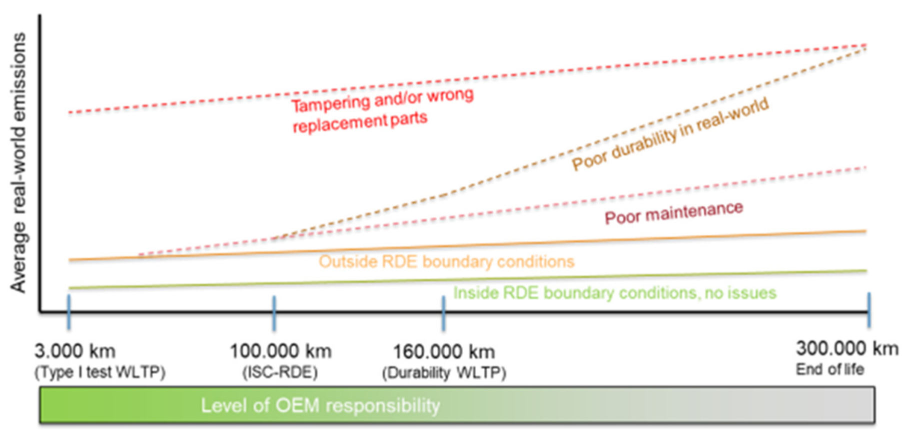

Figure 3-1: A schematic representation of the increase in emissions from gasoline cars due to various causes (TNO Report 2019 R10534). The manufacturer has less and less responsibility for these increases as mileage increases.

3.1 European type approval requirements (prototype tests)

Before a vehicle is put into production, it is checked during type-approval whether a prototype of the vehicle meets the legislated requirements. The vehicles that are tested should be representative of the vehicles that will later appear on the road in larger numbers. In the type-approval procedure, there are a series of emission tests that the vehicle must comply with. The WLTP test is normative for CO_2 emissions and a number of air pollutants such as, PM (particulate matter), HC (hydrocarbons), and CO (carbon monoxide).

[10] Nederlandse wagenparksamenstelling 2016, TNO rapport 2016 R11872.

The RDE test on the road is normative for (PN) particle number and NO_x emission requirements. A separate WLTP low-temperature test at -7° C must ensure that no major deviations occur at low temperatures[11].

3.2 Conformity of production (quality control)

For each type of vehicle, samples must be taken from the vehicles produced to check whether they meet the emission requirements and the declared CO_2 values. This test programme contains by far the largest number of tests carried out on vehicles. This happens when the vehicles leave the factory and before they have been driven. These tests are intended to ensure that vehicles meet the legal requirements when they are first put on the road.

3.3 In-service conformity requirements (in normal use)

A manufacturer must ensure that vehicles continue to meet type-approval requirements in normal use. This only applies to vehicles that are in original condition, have been maintained and repaired according to the manufacturer's instructions when the on-board diagnostic system indicates this and for a limited part of the actual life span. The current European requirements only apply to the useful life of passenger cars and vans, which is set at 100,000 kilometres or five years. This limits the monitoring of vehicles for their whole lifespan. It is expected that this will be increased to 200,000 to 300,000 kilometres with Euro-7 legislation. These requirements are monitored by the type-approval authority in consultation with the car manufacturer. Since 2019, the inspection of vehicles in normal use is no longer just a matter for the manufacturer. Type approval authorities, market surveillance authorities and independent parties can also test vehicles.

3.4 Market surveillance requirements

In addition to checking In-Service Conformity within the framework of type approval the same emission tests have been made part of market surveillance, where independent inspection authorities check vehicles on a random basis.
This check goes beyond the formal requirements of the type-approval. These checks also include any modifications to vehicles and possible manipulation software from the manufacturer for new vehicles.

3.5 Periodic technical inspection requirements

After 100,000 kilometres, the checks on the compliance of the vehicles with regard to emissions cease in normal use, and only the PTI and the OBD are available to check the emission behaviour of the vehicle. In the Dutch PTI, a vehicle is subjected to a check on the permanent requirements as laid down in the *Voertuigen Regeling*. Since after 100,000 kilometres, or in the case of a broad interpretation of the type-approval at 160,000 kilometres, there is also no check on the functioning of the OBD, as is done within the framework of In-Service Conformity, the question then arises as to whether the OBD is the right basis for the PTI of older vehicles.

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[11] UNECE WLTP Task Force on Low Temperature Test (LowT TF) (wiki.unece.org)

The PTI requirements follow from the minimum requirements set out in the European Directive for Periodic Inspection 2014/45/EU[12][13]. In this adaptation of the old Directive 2009/40/EC, which since May 2018 is no longer in force, the role of the OBD was increased, at the time under the assumption that this was more effective. The Dutch PTI requirements correspond to the minimum requirements in the European Directive for petrol cars. For diesel cars, the Netherlands has introduced a more effective test for particulate filters than is described in the European Directive. The test of a particulate filter is carried out in the Netherlands with a particle counter.

3.6 Roadside inspections

The roadside inspections are mainly intended for heavy road vehicles and for safety. For light vehicles, this is limited to a number of visual inspections similar to the PTI. For most problems, a referral is made back to the PTI. A vehicle can then be given WOK status (*wachten op keuring* - waiting for Inspection), after which a technical inspection at a RDW inspection station is required before the vehicle can be used again.

The European Directive on the technical roadside inspection of commercial vehicles circulating in the Union applies to heavy commercial vehicles[14] but allows Member States to inspect vans and passenger cars as well.

3.7 Developments of European legislation

Currently, vehicle emissions, which are emitted over the lifetime of the vehicle, have the attention of Brussels: Firstly, in July 2023, the DG-GROW is expected to propose to extend the type-approval requirements for vehicles to a longer useful life than the current 100,000 kilometres and five years. This will include consideration of the difference in assessment between vehicles that meet type-approval requirements and those that are not in original condition or well-maintained and are still allowed to drive on public roads. Secondly, the European Commission, through its DG-MOVE department, has announced[15] that it will review the periodic inspection directive. Specifically, it states: "to ensure the environmental performance of vehicles during their lifetime. [...] to perform meaningful emission tests during vehicle inspections." Thirdly, under UNECE[16], partly at the insistence of the CITA, the globally cooperating parties for periodic inspections, work is being done to improve the emission behaviour of vehicles over their entire lifetime ("whole lifetime"). The Netherlands has expressed its support for such improvements.

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[12] Directive 2014/45/EU of the European parliament and of the council on periodic roadworthiness tests for motor vehicles and their trailers.

[13] Beleidsstudie naar het voorkomen en bestrijden van emissiefraude bij wegvoertuigen, TNO & VUB voor Vlaams Planbureau voor de Omgeving, Brussel, 2020.

[14] Directive 2014/47/EU

[15] Revision of the Directives of the Roadworthiness Package, Ares (2021)6015595 - 04/10/2021.

[16] ECE/TRANS/WP.29/2021/148, Proposal for a Framework Document on Vehicle Whole-Life Compliance

4 Approaches for detecting vehicles with defects

Detecting defective diesel particulate filters is easier than detecting defective three-way catalytic converters. With a defective particle filter, particulate emissions are always increased, regardless of the conditions and use of the vehicle. A particulate filter test at idling speed is indicative of on-road emissions. For petrol cars, emissions vary greatly, both with conditions and over time under the same conditions. This variation makes it difficult to detect any defects in the exhaust aftertreatment system. A study in 2018 showed that of the 50 vehicles tested with high mileage, 6% were responsible for 36% of the total NO_x emissions. Defective vehicles therefore have a major impact on average NO_x emissions.

4.1 Execution of emission tests during the PTI

There are several aspects to be taken into account when detecting vehicles with systematically high emissions. Firstly, a test with a stationary vehicle, such as in the garage during the PTI, is not necessarily representative of the average emissions of the vehicle on the road. Secondly, a short test, including on road measurements, may not be representative of average vehicle emissions because emissions from petrol cars can fluctuate widely over time. Thirdly, problems with high emissions from petrol cars can have different causes and therefore different characteristics in terms of exhaust gas composition.

The simplest problem with the three-way catalytic converter is a problem with the catalytic converter surface itself[17]. If there is no longer any conversion in the catalytic converter from harmful to harmless substances, all emissions are permanently increased. A CO test may be able to detect this. High NO_x emissions are probably caused by a problem with the control of the catalytic converter and the lambda sensor. This sensor is used to very precisely, within narrow margins, achieve an optimal air-fuel ratio (lambda) in the engine of 1.00, which is necessary for a very efficient operation of the three-way catalytic converter. If NO_x emissions are increased, CO and hydrocarbon emissions are unlikely to be significantly increased. A CO test is therefore not indicative of high NO_x emissions. The current PTI test, in which the lambda value may be a maximum of 1.03, is too broad to detect this[18].

4.2 Remote sensing measurements

Remote sensing has been used for decades to detect defects that lead to increased emissions. In America, there are states where several low readings at a road portal can lead to an exemption from the PTI test. At the same time, car drivers with high emissions are warned about possible problems.

In Europe, there has only been a long-term structural measurement campaign in Zurich. Measurements from a fixed station have been used to investigate whether high emissions are repeated.

[17] Augmented emission maps are an essential new tool to share and investigate detailed emission data, H2020 project uCARe deliverable report D1.2 (www.project-ucare.eu, GA 815002)
[18] On road emissions of 38 petrol vehicles with high mileages, TNO rapport 2020 R11883.

This showed that most vehicles with high readings on one day had low emissions the next day. A connection between garage visits and measured emissions also turned out to be very weak.

Remote sensing measurements in Flanders also showed limited correlation between successive measured values on the same car[19]. On the motorway, driving conditions seem to be the most constant between different days and measured values. This is especially true for diesel vehicles equipped with SCR, which is warm and functions well on the highway. This can be used to detect SCR fraud and malfunctions. For petrol cars with defects, this does not seem to be a good detection method.

In America, developments are ongoing. In several places, special test rigs are being set up in a tent. Vehicles drive into a tent and remain there for a while with the engine on. In the tent, the exhaust gas is extracted and analysed. In some cases, this is used for preventive maintenance, and in other cases to subject vehicles to closer examination.

In Europe, most parties in the field of remote sensing work together in the European Horizon 2020 research project CARES[20]. In this project all applications of remote sensing are present, also those used in support of PTI. There are still limited results on this specific research question of whether remote sensing can be used to support the PTI. The progress of the CARES research project is hampered by the COVID-19 pandemic.

4.3 Roadside inspections

During roadside inspections, vehicles may be subject to an unexpected roadworthiness test. In the European framework[21], this inspection is required only for heavy goods vehicles on the road. However, the European framework does not prevent vehicles outside this category from also being inspected. Lorries subjected to a control are first subjected to a visual inspection. The inspection for irregularities includes the exhaust system and smoke density or concentration of CO for diesel and petrol vehicles respectively. For vehicles equipped with an emission control system, the CO measurement at idling speed must not exceed 0.5% vol. At an engine speed of at least 2000 rpm, it must not exceed 0.3% vol. The lambda value measurement, for petrol cars, must not deviate more than 0.03 from 1.00.

4.4 Registration of problem cases

Problems, such as defects that lead to high emissions, can occur with specific types of vehicles, brands or techniques used to reduce emissions. For example, some types of diesel particulate filters fail sooner than others[22]. Another example is the increased risk of theft of the three-way catalytic converter for certain brands.

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[19] Analysis of the 2019 Flemish remote sensing campaign, Vlaams Planbureau voor Omgeving, Brussel, 2020.
[20] https://cares-project.eu/
[21] COM/98/0117
[22] Follow-up research into the PN limit value and the measurement method for checking particulate filters with a particle number counter, TNO rapport 2020 R10006.

Problem tracking and inventorying can help reveal these weaknesses and facilitate risk-based assessment. This will increase effectiveness and probably reduce costs. One possible approach is to keep track of all PTI test results in a centralised database so that the database can be used for statistical analysis.

4.5 Inferior replacement parts

In a communication with the authors, the Dutch Human Environment and Transport Inspectorate shared some of its experiences. In the course of its work, it has observed that replacement parts, in particular three-way catalytic converters, are in circulation that do not reduce emissions at all. The fitting of proper replacement parts would lead to NO_x emissions of 2000 mg/km, a factor of 20 times higher than the average. These are the emission levels associated with vehicles built before 1987, before the three-way catalytic converter was widely introduced. The extent of the problem is not known, but if even 1% of vehicles drive around with an empty shell instead of a properly functioning catalytic converter, this has a significant impact on total NO_x emissions. An emissions test in the PTI will also detect this problem, but only at a later stage, when the vehicle with the inferior catalytic converter is on the road and eligible for a PTI test.

5 Further elaboration on testing of petrol cars

The current PTI tests and checks for the operation of three-way catalytic converters on petrol cars are not effective in detecting defects and the associated high emissions. In the first TNO study in 2018 of petrol cars, all vehicles with high NO_x emissions successfully passed the PTI test. In some cases, this PTI check was limited to reading the OBD system. In the second study, in 2020, an actual PTI emissions test was also carried out, even if the OBD did not give any error codes. The tests were in accordance with the PTI test, but no vehicle with high NO_x emissions failed the test[23].

The legal requirements concerning the environment are covered by the permanent requirements of the Vehicles Regulation[24]:

1. At idling speed: 0.3% vol. of carbon monoxide, if the vehicle was put into service after 30 June 2002;
2. At increased speed: 0.2% carbon monoxide by volume, if the vehicle was put into service after 30 June 2002, whereby the lambda value must lie between 0.97 and 1.03.

Petrol passenger cars with a maximum permitted mass not exceeding 3,500 kg, which were put into operation after 31 December 2005, are not tested during the PTI, but the OBD system is read out. Only if the read-out fails or if emission-related error codes are found, will an emission test be carried out, as described in the Vehicles Regulation:

“In deviation from the previous paragraphs, for vehicles equipped with an emission-related OBD system, it is permissible to carry out [...] by reading out the OBD system with the help of the reading device. The display may contain the P code, a descriptive text or a combination of both. Compliance with Article 41 is achieved if there is a faultless OBD system. If emission-related fault codes are detected or the readiness test is not completed, an assessment shall still take place in accordance with paragraphs 1 to 8 of this Article.”

In principle, therefore, a vehicle cannot fail a PTI test by means of an OBD readout alone, but a vehicle can pass a PTI test based on such a readout.

The test was developed when the three-way catalytic converter was introduced on petrol cars in 1992. Since then, only the values and procedures have been tightened. At the time, malfunctioning catalytic converters and malfunctioning lambda control were the main problems. Note that an exhaust emission test existed before this regulation. Based on an equivalence assessment, the emission test was replaced at the time by reading the OBD. One of the reasons for this was that the emission test was considered too cumbersome.

Later, the emission test was reintroduced for the situation where the OBD check was unsuccessful or emission-related fault codes were stored in the OBD.

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[23] On road emissions of 38 petrol vehicles with high mileages, TNO rapport 2020 R11883.
[24] Regeling voertuigen: https://wetten.overheid.nl/BWBR0025798/2022-01-01

The European PTI directive allows the introduction of an improved emissions test for checking the operation of three-way catalytic converters if this becomes available as a result of progressive insights.

5.1 OBD reading in combination with an emission test

In the current PTI, after a visual inspection and in the absence of emission-related fault codes in the OBD, an emission test no longer needs to be carried out after passing the readiness test. Making the emission test mandatory in the PTI, regardless of the results of the OBD, is a simple improvement to the PTI.
This can be done with current equipment and will improve the chances of finding major problems with high emissions. Detection of the reduced performance of the three-way catalytic converter can be further enhanced by limiting pre-conditioning, by driving the vehicle around until the catalytic converter is very warm and functions better.

Six of the 38 vehicles (16%) in the 2020 study passed the current PTI with increased NO_x emissions, around four times the average emissions[25]. Some of these vehicles would be rejected using an emissions test.

The test procedure itself allows the engine and three-way catalyst to be warmed up considerably prior to the test, for example by driving fast and dynamically, thus improving the performance of the three-way catalytic converter. An adaptation of the test procedure should prevent this, so that normal operation of the catalytic converter is tested.

5.2 Tightening of the lambda value

The lambda value in modern vehicles varies between 0.99 and 1.01. The limits of 0.97 and 1.03 will only detect the most serious problems. A tightening of the limits to 0.99 and 1.01 might be a simple adjustment to the PTI test, which could detect some of the problems. Directive 2014/32/EU prescribes the minimum accuracy and resolution of an exhaust gas tester. Further research is needed to verify that these accuracies are sufficient for a possible tightening of the limit values. An alternative would be to use a separately monitored lambda sensor. The lambda value must be displayed with a minimum resolution of 0.001. Two of the 38 vehicles investigated (5%) could thus be identified as high emission vehicles. These vehicles have emissions between 264 and 1267 mg NO_x/km. Repairing these vehicles yields a potential saving of 244 to 1180 mg NO_x/km per vehicle for 2.5% of the vehicles. This is at a minor increase in cost for the test. An interim solution is a follow-up test in the PTI if the lambda values are not in a close range. This could be a specific check of the lambda sensor itself. The exact savings potential must be demonstrated by means of follow-up measurements.

5.3 Inspection of the lambda sensor

High NO_x emissions are mainly related to a lambda value greater than 1.00. This is normally not related to a high CO value, so this problem will not be detected.

[25] European Directive 2014/32/EU

This is normally not associated with a high CO value, so the CO test will not detect this problem. The tightening of the lambda value may not detect all problems with the lambda control. A separate test of the lambda sensor itself, as a critical part of the operation of the three-way catalytic converter, may be better suited to pinpoint specific problems. Such a test could compare the lambda value communicated over the OBD port with a lambda measurement on the exhaust gas tester. The lambda sensor remains in the vehicle. The check of the lambda sensor may indicate that the sensor needs to be replaced for the three-way catalytic converter to work properly. A defective lambda sensor was found in two of the 38 vehicles tested.
If there are indications of a defective lambda sensor, for example due to deviating lambda values, this is a possible next step to determine whether the lambda sensor needs to be replaced. This test does not have to incur additional costs. Lambda measurements are available on existing exhaust gas testers. Only other parameters need to be looked at.

5.4 Cold start test

In some cases, the three-way catalytic converter no longer functions properly.
The effectiveness of the catalytic converter surface may have been reduced.
Or the original catalytic converter may have been replaced by a replacement catalytic converter which works less well or not at all. The harmful substances are then no longer converted, even if the lambda value fluctuates precisely around 1.00. The proper functioning of the catalytic converter is critically tested during the cold start of the engine. A good catalytic converter will reduce emissions within 20 seconds. Catalytic converter defects can be recognised both by the length of time it takes for the catalytic converter to become effective and by the concentration levels of pollutants over the course of the test. Of the 38 vehicles tested, one vehicle was able to recognise a defective catalytic converter with this method. After replacement of the catalytic converter, an emission reduction of 93% is possible. It is possible to expand the measuring equipment with a NO_x measurement, and to map out the time dependence.

The current PTI measurement equipment can be adapted for this purpose.
The additional costs for this test are therefore relatively limited. What the effective limit values are for emission levels and time dependence should still be investigated with follow-up measurements. Emissions during the cold start are very high and form a substantial part of total emissions from clean vehicles. It is in the public interest to pay attention to cold start emissions because of their impact on health and the environment, also because these emissions mainly occur at homes.

5.5 The second life or 160,000-kilometre test

Since the manufacturer's responsibility ends after 160,000 kilometres, a one-off comprehensive inspection of vehicles in the first PTI after the 160,000-kilometre mark might be a good starting point for the second half of the vehicles' lifetime. Given the durability requirements of emission control technology up to 160,000 kilometres, there is a chance that some of the technology will no longer function properly. Identifying these defects once and having them replaced with sound parts will lead to improvements for a longer period of time. In the four repaired vehicles from a previous study, NO_x emissions were reduced by 37% to 93% after repair. This should be further investigated by means of follow-up measurements.

Such a more comprehensive test could consist of the above tests, but it is possible that tests to detect faulty components would be too complex, too expensive or too complicated to carry out in the current PTI. In that case, it could be considered to place this one-off test in specialised PTI approval centres throughout the vehicle's lifetime. It may be necessary to use a roller dynamometer test set-up in order to get a good coverage of all normal driving conditions. Centralising the 'second life test' limits the costs, probably to a few hundred Euros per test.

5.6 Market surveillance of the OBD

The mandatory systems in the OBD for detecting defects are largely covered by type approval and are checked within that framework. The question is whether these systems will still function properly after 100,000 or 160,000 kilometres.
In principle, switching off or reducing the OBD systems at higher mileages, and thus not detecting defects with high emissions, is a form of illegal manipulation that can be enforced[26]. Since 2019, the Netherlands has been required to monitor such matters.

5.7 Market surveillance of replacement parts

If inferior quality parts are fitted when petrol cars are repaired, emissions can be higher as a result. Replacement parts must meet European requirements, but there appears to be a market for poor, uncertified parts. The reason is that a three-way catalytic converter contains precious metals which make a good catalytic converter expensive. The price starts at around €300, while an empty shell, which looks the same on the outside, costs around €50.

There are signals from the market that inferior parts are being offered and fitted. The impact of this is considerable at the vehicle level. A single car that drives 100,000 kilometres with a non-working catalytic converter easily produces 0.2 tonnes of NO_x. So, 5,000 vehicles without functioning catalytic converters can emit 1 kt of NO_x in the second half of their life.

5.8 Conclusions

The proposed approaches and tests can also be combined. A reintroduction of an emissions test for petrol cars with three-way catalytic converters, instead of or in addition to OBD reading, can be done quickly. Tightening up the lambda rejection standard and restricting the conditions under which the test may be carried out can, in principle, also be implemented quickly. Performing a new lambda sensor test can, possibly at a later stage, be carried out as an addition to the original emission test. The 'cold start test' requires further development but makes the PTI more focused on the impact of vehicle emissions on the environment and health.
The 'second life test' is strongly linked to good maintenance and high-quality replacement parts. This fits in with a broader approach.

The possible extra costs of a new PTI test can be offset against the costs of damage caused by emissions. The social damage per kilogram of NO_x emissions was established by CE Delft at €34.70[27] for the (traditional) NO_x problem.

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[26] European Regulation (EU) 2018/1858
[27] Handboek Milieuprijzen 2017, CE Delft 2017

This does not include the social damage associated with construction project delays, however. Measures with the potential to save one kton of NOx emissions or more may thus cost €35 million, making measures in the PTI to reduce emissions rapidly cost-effective.

6 Conclusions

Detecting petrol vehicles with high NO_x emissions only makes sense if a vehicle is tested in accordance with legal requirements, on the basis of which repairs can be enforced. At present, only the PTI, which imposes permanent requirements, offers the possibility to conclusively determine defects throughout the entire lifecycle of a vehicle. The test procedure in the PTI, which checks the proper functioning of the three-way catalytic converter with lambda sensor, can be improved. In some cases, this can be done on the basis of the current rules and measuring equipment; in other cases, it will require new and perhaps more advanced equipment in specialised PTI inspection companies.

Vehicles registered from 1 January 2006 onwards do not now need to undergo an emissions test if the OBD has been successfully read without any emission-related fault codes. Reintroducing the emission test into the PTI, also for newer vehicles, will detect the most serious problems. If the limit values for the lambda values are subsequently tightened from 0.97-1.03 to limit values in the region of 0.99-1.01, a number of defective vehicles will be detected. Restricting the conditions under which the emissions test may be carried out may also help to detect more defective vehicles.

At a later stage, problems with the lambda sensor of newer vehicles with OBD can be identified more easily by checking the lambda value in the OBD by means of a measurement in the exhaust. The need for the replacement of a lambda sensor is thus effectively established.

Given the high emissions from petrol cars during a cold start, a targeted cold start test in the PTI is a way to broadly identify problems with the three-way catalytic converter. The test procedure will have to be developed further but does not require new testing equipment in the PTI, except that the measurement of NO_x concentrations may have to be added. Such test equipment, the so-called five-gas tester, already exists.

Given that durability requirements for the vehicle manufacturer for the three-way catalytic converter apply up to 160,000 kilometres, a separate more extensive PTI test once after 160,000 kilometres is an option to bring a vehicle into good condition for the second half of its service life. This involves replacing parts that no longer meet the applicable requirements after the 160,000-kilometre threshold.

In addition to possible adjustments to the Dutch PTI test, the Netherlands is making efforts at a European and UNECE level to increase the life cycle requirements and inspection to 200,000 kilometres and beyond. The inspection possibilities must be expanded and simplified. There are also developments concerning the European framework and UNECE regulations for periodic inspections. The insights from the Netherlands can provide direction for an effective new approach to PTI and, with that, lay a good foundation for a new PTI test that results in low emissions over the entire life span of a vehicle.

7 Signature

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TNO

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