Urbanisation
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10

TNO report

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Roadworthiness Test Investigations of Diesel Particulate Filters on vehicles

Date	19 June 2015
Author(s)	Gerrit Kadijk Jordy Spreen
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Sponsor	Mr. H.L. Baarbé Ministry of Infrastructure and the Environment Directorate-General for Environment and International Coordination PO Box 20901 2500 EX THE HAGUE The Netherlands
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Samenvatting

Achtergrond:
Vanaf 2002 worden in Nederland in personenwagens die zijn uitgerust met een dieselmotor gesloten roetfilters gemonteerd en tegenwoordig zijn alle nieuwe lichte voertuigen met dieselmotor af-fabriek voorzien van een gesloten roetfilter.

Het is inmiddels bekend dat kleine lekkages in gesloten roetfilters leiden tot een significante toename van de deeltjesemissie in de praktijk [1]. Een kleine lekkage leidt al gauw tot een daling van het filtratierendement van 99.5 naar 97%. Bovendien zijn er aanwijzingen dat deze roetfilters worden verwijderd of opzettelijk vernield om op onderhoudskosten te besparen. Soms gebeurt dit in combinatie met chip-tuning (aanpassing van de motorafstelling) die ook het Electronische On Board Diagnose systeem (EOBD) deels uitschakelt waardoor storingen niet aan de berijder worden gemeld. Vanwege deze situatie is een controle van de werking van een gesloten roetfilter in een roetfiltertest in een Algemene Periodieke Keuring (APK) te overwegen.

Doel en aanpak:
Het Ministerie van Infrastructuur en Milieu heeft aan TNO gevraagd de effectiviteit van mogelijke roetfiltertesten te onderzoeken. Hiervoor zijn 400 hoofdzakelijk Euro 5 personen- en bestelwagens aan verschillende rookemissietests onderworpen. Deze testen zijn verspreid over geheel Nederland uitgevoerd door steekproefcontroleurs van de Rijksdienst voor het Wegverkeer (RDW), dit als aanvulling op hun reguliere werkzaamheden.

Naast het verkrijgen van inzichten in het aantal voertuigen met verhoogde deeltjesemissies zijn de testresultaten ook gebruikt voor de ontwikkeling van een aangepaste APK-rookemissietest die het mogelijk maakt voertuigen met defecte of gedemonteerde roetfilters te herkennen. De huidige APK-roetmeting is daartoe in het algemeen niet in staat.

De volgende vijf rookemissietests zijn uitgevoerd op de voertuigen:

1. Visuele inspectie op aanwezigheid van het filter
2. Een veegtest in de uitlaatpijp met een wit papieren doekje
3. Uitlezing van mogelijke foutcodes van het EOBD systeem
4. Vrije acceleratie test met een wit papieren doekje om de uitlaatopening
5. Rookemissietest met opaciteitsmeter (vrije accelaratie test).

Conclusies:
De testresultaten van de met gesloten roetfilter uitgeruste voertuigen hebben geresulteerd in de volgende conclusies:

- Ten minste 21 van de geteste voertuigen (6%) hebben verhoogde rookemissies, in die mate dat mag worden aangenomen dat de gesloten roetfilters beschadigd zijn of verwijderd. Al deze voertuigen (voor zover er sprake was van readiness) voldeden, echter, aan de criteria van de EOBD-uitlezing, dit geeft aan dat EOBD-uitlezing niet toereikend is voor detectie van defecte of verwijderde roetfilters.

- De vrije acceleratietest die met opaciteitsmeter wordt uitgevoerd blijkt geschikt voor detectie van defecte of verwijderde roetfilters. Voor het verkrijgen van stabiele testresultaten is wel een korte pre-conditionering van het uitlaatsysteem noodzakelijk.
- De eerdere vrees dat de huidige APK-roetmeters onderin hun grote meetbereik onvoldoende nauwkeurig zouden zijn voor een zinvolle test aan een auto met gesloten roetfilter is mogelijk ongegrond.
- Als een APK testprocedure voor de bepaling van rookemissies uit meerdere deeltesten bestaat zal de volgorde van deze testen gespecificeerd moeten worden. De volgorde van de testen moet dusdanig gekozen worden dat de historie van een uitlaatsysteem (opgeslagen roetdeeltjes) geen invloed heeft op het testresultaat.
- Vrije acceleratie rookemissietesten die worden uitgevoerd met witte tissues zijn te complex en tijdrovend, en bieden dus geen meerwaarde noch alternatief voor een opaciteitsmeting.

Aanbevelingen:
In dit onderzoek is een grenswaarde voor rookemissies van 0.50 1/m gekozen. Als het testresultaat hoger dan de aangegeven waarde ligt, is er in dit onderzoek sprake van een afkeuring. Voor een nieuwe testprocedure is een grenswaarde voor rookemissies nodig die meer onderbouwd is zodat onterechte goed- of afkeur wordt geminimaliseerd. Hiervoor wordt vervolgonderzoek in de praktijk aanbevolen dat resultaten van meer voertuigen bevat dan dit onderzoek, en waarbij door middel van een meting van het deeltjesaantal met meer zekerheid wordt vastgesteld of sprake is van een beschadigd of verwijderd roetfilter.

Summary

Background
Since 2002 wall flow type diesel particulate filters (DPF) on light duty vehicles have entered the Dutch market. Nowadays all newly-registered light duty diesel vehicles are being equipped with a DPF.

It is known that possible losses in filtration efficiency significantly affect real-world PM emissions [1]. Typically, efficiency losses encountered amount to 2,5%, with filter efficiencies dropping from 99.5 to 97%. Moreover, there have been indications of traps being replaced by dummies or deliberately destroyed to avoid the cost of cleaning, maintenance or replacement or as part of chip tuning of the engine, while simultaneously adapting the OBD software to avoid detection. Therefore, in order to verify that DPF's reduce the emissions of PM while the vehicle is operated, a check of their functionality in roadworthiness tests is considered.

Aim and approach
The Ministry of Infrastructure and the Environment asked TNO to investigate the effectiveness of such possible DPF tests. To this end, 400 light-duty vehicles with diesel particulate filters were tested using different smoke test procedures. The vehicles were mostly Euro 5 class vehicles. The tests were performed by Dutch RDW-inspectors of the Dutch roadworthiness authorities (RDW), who ran these additional emission tests during supervision of periodic technical inspections (APK). The tests occurred in different vehicle maintenance workshops in the Netherlands.

Apart from providing insight into the number of vehicles with increased PM emissions, the test results were also used to develop a new roadworthiness smoke emission test procedure able to identify vehicles with a malfunctioning or removed DPF. Generally the current roadworthiness test procedure is not able to identify such failures.

All vehicles were subjected to five different tests:

1 Presence of DPF with a visual inspection;
2 A tailpipe wipe test with a white tissue;
3 Reading of EOBD failure codes;
4 Free acceleration smoke emission test with white tissue at the tail pipe;
5 Smoke emission test with opacity meter.

Conclusions
The results of the above tests lead to the following conclusions for roadworthiness testing of diesel vehicles with diesel particulate filters (DPF):

- At least 21 of the assessed vehicles (6%) showed elevated smoke emissions. This indicates that the Diesel Particulate Filters of these vehicles were either damaged or removed. The EOBD test results of these vehicles (in case of readiness), however, passed all criteria of the EOBD-reader, which indicates that EOBD tests are not suitable for detecting failures of Diesel Particulate Filters.

- The free acceleration smoke emission test with an opacity meter is a good means to detect malfunctioning or removed DPF's. In order to stabilise the test results, pre-conditioning of the exhaust is however needed.

- In the past some fear of inaccuracy of low readings of smoke meters in the lower measuring range was grown. Possibly this fear is unsound.

- If a roadworthiness test procedure consists of several different tests, the test sequence of the different tests must be specified. The sequence should be such that it eliminates history effects of the exhaust system of the vehicle.

- For roadworthiness purposes, free acceleration smoke emission tests with white tissues are too complex and time consuming.

Recommendations

In this research project a smoke emission limit value of 0.50 1/m has been chosen. If the test result exceeds this value the vehicle has a 'fail'. In case of implementation of a new smoke emission test procedure this limit value must further evaluated. This will probably result in less dishonest fail or pass test results. Further practical research with more vehicles is recommended which can be extended with particulate number tests which will result in more reliable pass or fail statements of removed or damaged soot filters.

Contents

Samenvatting **2**

Summary **4**

1 Introduction **7**

2 Objectives **8**

3 Test activities **9**
3.1 Specification of emission tests 9
3.2 Selection of test samples 12

4 Results **13**
4.1 Validity check of tested vehicles 13
4.2 Visual tests 13
4.3 Tailpipe wipe tests 13
4.4 EOBD tests 14
4.5 Free acceleration smoke emission tests with white tissue 15
4.6 Smoke emission tests with opacity meter 16
4.7 Summary of the results of the DPF tests 16
4.8 Combined results of DPF tests 17

5 Discussion **19**

6 Conclusions **20**

7 Recommendations **21**

8 References **22**

9 Signature **23**

1 Introduction

Since 2002 wall flow type diesel particulate filters (DPF) have entered the Dutch market. Nowadays all newly-registered light duty diesel vehicles are being equipped with a DPF.

It is known that possible losses in filtration efficiency significantly affect real-world PM emissions. Typically, efficiency losses encountered amount to 2,5%, with filter efficiencies dropping from 99.5 to 97%. Which means that PM emissions increase six-fold. Moreover, there have been indications of traps being replaced by dummies (empty cans) or deliberately destroyed internally to avoid the cost of cleaning, maintenance or replacement or in conjunction with chip tuning of the engine, while simultaneously adapting the OBD software to avoid detection. Therefore, in order to verify that DPF's reduce the emissions of PM while the vehicle is operated, a check of their functionality in roadworthiness tests should be considered.

Currently, the roadworthiness test method for diesel vehicles without DPF has been based on engines with relatively high PM emissions and the measuring range of current test equipment poorly matches the actual range of PM emissions of DPF-equipped vehicles. The optical test method currently used is based on opacity or light absorption. The smoke emissions in a free acceleration test of most vehicles equipped with a DPF do not exceed the detection limit of current test equipment. And even for vehicles of which the trap has been removed or destroyed, the opacity value often stays below the reference value determined during the type approval, which includes a margin error of 0.5 m^{-1}.
These relatively low smoke emissions of modern diesel vehicles, either with or without DPF, call for the development of a new DPF Roadworthiness Test Procedure (RTP).

In a former project [1] special attention was given to the smoke emission test and the required test equipment which is able to measure the low smoke emissions of modern vehicles. Following up on this work, the Dutch Ministry of Infrastructure and the Environment commissioned a second project for development of a DPF Roadworthiness Test Procedure. This report is a second step in the development of this test procedure and details the investigation of possible DPF roadworthiness tests.

In order to investigate the effectiveness of DPF tests, four hundred vehicles with diesel particulate filters were tested using different smoke test procedures considered suitable to be applied in an roadworthiness test environment. The tests were performed by inspectors of the Dutch roadworthiness authorities (RDW), who ran these additional emission tests during supervision of periodic technical inspections (APK). The tests were performed in different vehicle inspection and maintenance workshops in the Netherlands.

2 Objectives

The objectives of this project are as follows:

- To determine the share of failing or missing diesel particulate filters in the fleet of light duty vehicles with diesel engine.
- To investigate different potential roadworthiness emission test procedures for vehicles type-approved with “wall flow” diesel particulate filters (DPF). Wall flow type means a particulate number filtration efficiency of more than 99%.
- To determinate the filtration performance of Diesel Particulate Filters and a definition of pass/fail DPF emission levels.

Remark: Participation of vehicle owners in the tests was on a voluntary basis. A small number of owners rejected cooperation for unknown reasons. This means that the final results might underestimate the occurrence of removed filters.

3 Test activities

For the development of a modified roadworthiness smoke emission test procedure five different tests were defined and conducted:

1. Visual test
2. Tailpipe wipe test
3. EOBD test
4. Free acceleration smoke emission test with tissue
5. Free acceleration smoke emission test with opacity meter

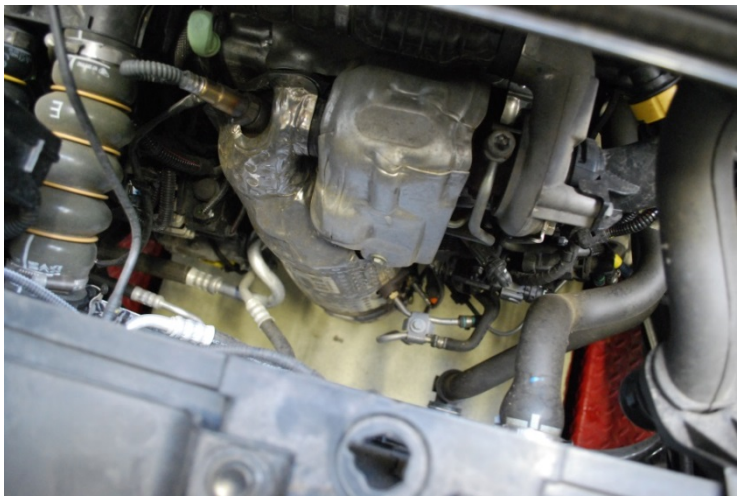
Periodic roadworthiness tests of Dutch vehicles are being executed by certified technicians in vehicle maintenance workshops. On average 3 percent of these roadworthiness tests are random sample checked by an inspector of the Dutch roadworthiness authorities (RDW). This experimental test programme with modified smoke emission tests was carried out during such random test activities by RDW-inspectors.

Diesel vehicles equipped with a DPF have extremely low smoke and PM emissions as all soot is stored in the DPF. From time to time the DPF must be regenerated and the stored soot is burned. Even during DPF regenerations PM emissions are very low. As soon as a certain DPF-crack or leakage occurs, PM will pass the DPF and leave the tailpipe. Some soot will be stored on the inner walls of the exhaust system. In close cooperation with the Ministry of Infrastructure and the Environment, TNO designed five tests to detect DPF failures or DPF removals.

3.1 Specification of emission tests

Five types of tests were conducted:

1. Visual test: In a first inspection of a vehicle, the visual presence of a DPF was checked. In case of a DPF removal and installation of a straight pipe, the absence of a DPF justifies a ‘fail’ of the roadworthiness test. In a second inspection, the RDW-inspector knocks on the housing of the DPF. A relatively ‘hollow’ sound while doing so might indicate a possible DPF removal.



2. Tailpipe wipe test: In this indicative test a white tissue is wiped at the inner tailpipe, as shown in Figure 1. The collected soot on the tissue might be an indication of a DPF failure or removal. However, over a longer period of time very small DPF leaks will pollute the internal exhaust system as well. This means a polluted tissue does not necessarily indicate a malfunctioning DPF, but gives motive for further inspection.

Figure 1: Tailpipe and result of inner tailpipe test

3. EOBD test: The On Board Diagnostic system of a vehicle monitors some conditions of the DPF. A simple check at the start of the roadworthiness test will gain information about stored failure information. Certain emission-related malfunctions may be stored in the memory of the engine management system and these may indicate DPF failures. Before the start of the EOBD test, the system checks the status of the 'readiness test'. In a readiness test the EOBD system compares a package of predefined speed and load conditions of the engine which are passed in a type approval emission test with the history of the speed and load conditions of the test vehicle. If the test vehicle has run all predefined speed and load conditions, the readiness test is passed. If the EOBD test fails, it must be replaced by a smoke emission test using the opacity smoke meter.

Figure 2: EOBD reader, displaying the message "No error codes".

4. Smoke emission test with white tissue: A free acceleration test of an engine starts at low idle speed and moves to high idle speed and back. During the test, the gear box is in the neutral position and the accelerator pedal is moved within 1 second to the maximum positionloading the engine by its own inertia. This yields a raise of the engine speed and, due to a shortage of combustion air, the engine generates a smoke peak. The emitted particulate matter is stored on a tissue which is mounted at the exit of the tail pipe (Figure 3). After the loading of the tissue it can be compared with a colour swatch which ranges from white to black on a 1-10 scale (Figure 4).

Figure 3: Tissue mounted on a tail pipe for a smoke emission test.

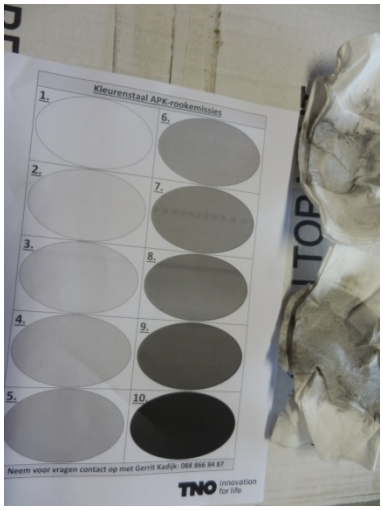


Figure 4: Colour swatch and loaded tissues.

5. Smoke emission test with opacity meter: The regular roadworthiness smoke emission test is carried out as a free acceleration test with an opacity meter, shown in Figure 5 and Figure 6. During the test, the engine runs from low-idle to high-idle speed within 1-2 seconds. This generates a smoke peak value. For stabilisation purposes the test must be repeated a few times until the readings are stable.

Figure 5: Opacity meter for a roadworthiness test.

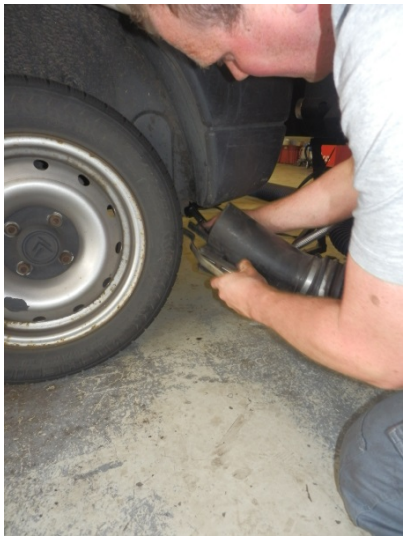


Figure 6: Installation of the sample probe for a smoke roadworthiness test.

3.2 Selection of test samples

In October 2013, during regular survey activities of the 20 RDW-inspectors, vehicles with DPF were selected for an extra smoke emission test program. On a voluntary basis, vehicle owners as well as owners/representatives of the maintenance workshops were invited to cooperate in this experimental test program. The RDW-inspectors work in different regions in the Netherlands and they performed the five emission tests per vehicle which are specified in section 3.1.

4 Results

4.1 Validity check of tested vehicles

Before analysing the test results, the properties of the tested vehicles were screened in detail. This led to the removal of the test results of 40 vehicles, as these vehicles were not equipped with a DPF. These vehicles were mostly Euro 4 class vehicles. Consequently, the data analysis was performed on test results of 355 vehicles. Table 1 reports the odometer readings of the selected vehicles.

Table 1: Overview of the number of tested vehicles.

Odometer [km]	Number of vehicles
0 – 50.000	31
50.000 – 100.000	93
100.000 – 150.000	118
150.000 – 200.000	82
200.000 – 250.000	23
250.000 – 300.000	6
300.000 – 350.000	1
350.000 – 400.000	1
Total vehicles	**355**

Remark: The durability type approval requirements of Euro 5 vehicles are linked to their first 160.000 kilometres. For roadworthiness tests no durability requirements are applicable. During a vehicle life time the limit values of the free acceleration smoke roadworthiness test are fixed. From the vehicle selection in this project, 257 vehicles had run less than 160.000 km; 98 had run more.

4.2 Visual tests

Visual tests were performed on all inspected vehicles. Two vehicles were not equipped with a DPF. The DPF of the first vehicle sounded hollow and smoke test readings ranged from 0,13 – 0,25 m^{-1}; this indicates a removal of the DPF. For the second vehicle, no comments are available. These two vehicles passed their EOBD test.

4.3 Tailpipe wipe tests

Table 2 shows the results of the tailpipe wipe tests. From the tested vehicles, 208 (62%) returned a ‘No’, indicating a clean tailpipe. 128 vehicles (38%) returned a ‘Yes’, indicating a black tailpipe. As said earlier, the dirt or soot in the tailpipe does not necessarily mean that the DPF is damaged, as soot may be collected over a longer period and this may be caused by very small leaks in the DPF. From the 128 vehicles ‘scoring’ a ‘Yes’, about 60 vehicles have very low smoke emission test readings (< 0.05 m^{-1}), which probably means their DPF’s are in good condition. 68 Vehicles (19%) showed a black tailpipe *and* elevated smoke emissions. In some way the DPF’s of these 68 vehicles needed further research.

Table 2: Test results of the tailpipe wipe tests.

Value	Black soot
No value	19
Yes	128
No	208
Total	**355**

4.4 EOBD tests

EOBD tests may result in messages or EOBD codes which indicate the technical condition of certain systems. Emission-related EOBD codes of engines with compression ignition are: P01xx, P02xx, P03xx, P04xx, P06xx or P0Axx.

An EOBD test can be performed after the ‘readiness test’ is completed. A readiness test is an on-board test that is performed during normal driving of a vehicle. In case of an NEDC test on a chassis dynamometer all needed speed and load conditions of the engine are performed and the readiness test is completed. In daily operation, the readiness could not be completed because the required engine speed-load conditions are not executed. In the vehicle selection of this project, 10% of the 355 tested vehicles run with a non-completed readiness test. In case of a non-completed readiness test in a roadworthiness test procedure, a free acceleration test with smoke emission test equipment must be performed.

Results of EOBD tests: In the executed EOBD tests, three vehicles (0,8%) produced emission-related malfunctions (P0128, P0340, P0673) and, for two of those vehicles, the corresponding smoke emission levels were very low (0.00 and 0.00 m^{-1}). From the third vehicle with a smoke emission level of 0.46 m^{-1} the glow plugs are replaced. The odometer readings of these three vehicles were over 200.000 km.

4.5 Free acceleration smoke emission tests with white tissue

Table 3 shows the test results of free acceleration smoke tissue tests of the 355 vehicles. 28 (8%) vehicles showed a high smoke emission; the tissues were loaded with a certain amount of soot (reading is > 4). The results might, however, not be reliable because the load on the tissues might be caused by stored soot in the exhaust system which is released during a test. Repeating the test a few times before installing the tissue would increase the reliability.

Table 3: Test results of free acceleration smoke tests with tissues.

Value	Number of vehicles
No test result	36
0	14
1	233
2	29
3	10
4	5
5	3
6	3
7	6
8	11
9	5
10	0
Total	**355**

In Figure 7 the correlation between results of the smoke tissue test and the opacity test are shown. The figure shows clearly that there is a bad correlation between these test results. This indicates that soot in the exhaust is stored over a longer period and is released in the smoke emission test with tissue.

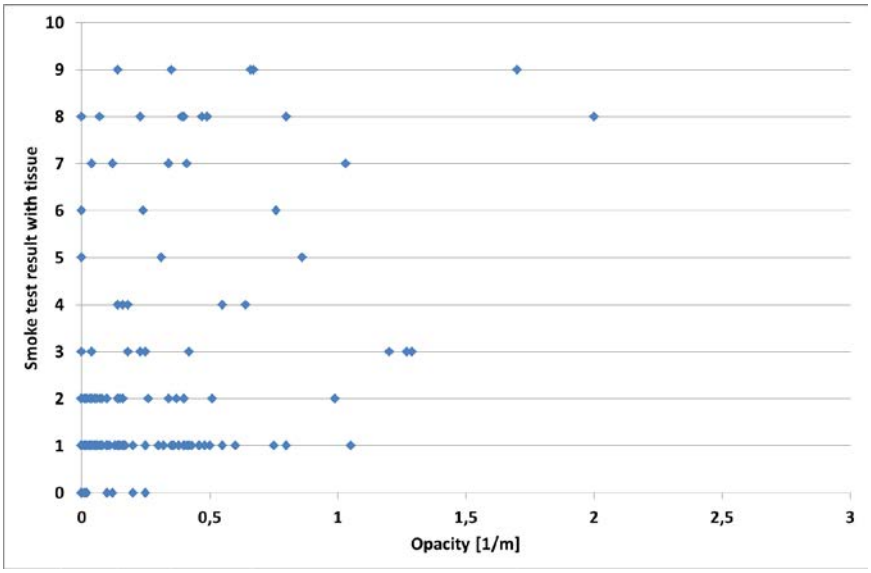


Figure 7: Correlation between smoke tissue test results and opacity test results

4.6 Smoke emission tests with opacity meter

In Table 4 two consecutive test results of free acceleration smoke tests with smoke meter are reported. A smoke emission of 0.50 1/m is considered as high and it is expected that these vehicles have a PM-emission that exceeds the type approval limit value. In the first test, 21 vehicles (5,9%) showed smoke emissions higher than 0.50 1/m. In the second test, 20 vehicles still had high smoke emissions. I.e. the smoke test results are stable and relatively high. This indicates a malfunctioning or removed DPF.

Table 4: Test results of two consecutive smoke tests with a smoke meter.

Value [1/m]	**Number of vehicles**	**Number of vehicles**
	First smoke test	**Second smoke test**
No test result	31	31
0,00 – 0,10	241	70
0,10 – 0,20	25	18
0,20 – 0,50	37	30
0,50 – 1,00	14	12
1,00 – 2,00	7	7
2,00 – 3,00	0	0
3,00 – 4,00	0	1
4,00 – 5,00	0	0
6,00 – 7,00	0	0
7,01 – 8,00	0	0
8,01 – 9,00	0	0
9,01 – 10,00	0	0
Total	**355**	

From this vehicle selection of 355 vehicles 31 vehicles were not tested in a free acceleration test with smoke meter. This means the calculation of the failing rate must be based on 324 vehicles and will increase from 5,9 to 6,5%.

4.7 Summary of the results of the DPF tests

Table 5 summarizes the smoke test results. The five different test methods resulted in 3 – 128 failures.

The 128 failed tailpipe tests are probably partly caused by released soot in the exhaust system. This soot may have passed the DPF because very small leakages in the DPF, occurring over a longer period of time. In this period, the inner walls of the exhaust system are covered with black soot. Apparently the results of this test method are related to a very long running period and do not yield a momentary result which is needed for a roadworthiness test procedure. From this point of view the tailpipe test with tissues is not suitable for roadworthiness test purposes because for every measurement a new tissue must be installed.

Six different failing vehicles were detected in three visual tests and three different EOBD tests. In the smoke tests using the opacity meter, 19-28 vehicles did not pass the test.

Table 5: Summary of test results.

	Test method	**Pass**	**Fail**	**No value**
		Vehicles		
1	Visual test	340	3	12
2	Tailpipe tests with tissue	208	128	19
3	EOBD tests	323	3	19
4	Smoke tests tissue	291	28	36
5	Smoke test 1 opacity	303	21	31
	Smoke test 2 opacity	109	19	227

4.8 Combined results of DPF tests

If the test results of the five test methods are combined a more thorough DPF assessment is built. To do so, the next four criteria were applied:

1. Result of first smoke opacity emission test (> 0.40);
2. Second smoke opacity emission test (> 0.30);
3. Smoke tissue test (> 2);
4. Negative trend of consecutive smoke emission readings (< 50%).

All test results of the 355 vehicles were screened according to these four criteria. If one of the criteria is met the DPF is assumed to be defect.
The results of Table 6 show 20 vehicles with DPF failures or DPF removals, this is 6% of the total amount of 355 samples. From these vehicles the results of the EOBD tests, the visual tests and the tissue wipe test are all positive. Together with four combined criteria this means that there is a clear indication of a DPF failure. However, it is expected that the real percentage of failures or removed DPF's is higher because the measuring data is not complete (results of smoke emission tests are missing) and a number of vehicle owners rejected participation in the tests of this project.

Table 6: Smoke emission test results of 21 suspected vehicles with DPF failures

Vehicle 1	1,7	1	0,5
Vehicle 2	1,29	0,83	0,73
Vehicle 3	1,27	0,84	0,72
Vehicle 4	1,2	1,1	1,1
Vehicle 5	1,03	1,01	0,97
Vehicle 6	0,86	0,73	0,68
Vehicle 7	0,8	0,63	0,68
Vehicle 8	0,76	0,97	0,68
Vehicle 9	0,67	0,55	0,57
Vehicle 10	0,66	0,65	0,45
Vehicle 11	0,49	0,58	0,6
Vehicle 12	0,49	0,4	0,32
Vehicle 13	0,47	0,45	0,48
Vehicle 14	0,42	0,42	0,41
Vehicle 15	0,41	0,34	0,32
Vehicle 16	0,4	0,77	0,98
Vehicle 17	0,39	0,41	0,4
Vehicle 18	0,35	0,56	0,77
Vehicle 19	0,34	0,28	0,36
Vehicle 20	0,34	0,31	0,27
Vehicle 21	0,72	0,64	0,60

5 Discussion

In a smoke emission roadworthiness test, the history of an exhaust system must be taken into account. A certain pre-conditioning of the exhaust is needed.
An exhaust system of a vehicle can store a significant amount of soot. In case of a small leakage of the DPF the soot which passes the DPF will partly be stored on the inner walls of the exhaust. Consequently, during a free acceleration roadworthiness smoke emission test, some of this stored soot may be released. In order to produce a representative and repeatable test result the free acceleration test must be repeated until the readings have reached a certain stable value. From this point of view, free acceleration smoke emission tests with white tissues and smoke meters are only possible after a certain pre-conditioning of the exhaust system. The pre-conditioning may consist of several free acceleration tests which must be repeated until the smoke emissions are stable. After this, the smoke emission test can be executed.

A tailpipe test with a tissue which is wiped over the inner surface cannot be conclusive.
At the start of a roadworthiness test a white tissue is wiped over the inner surface of an exhaust. The collected soot on the tissue may have been emitted over a longer period of time and may therefore only indicate a DPF leakage. This result does not yield information about the amount of leakage. This means this tissue test result is only a first indication of the status of a DPF. It indicates if a leakage is present but does not reveal any information on the size of the leakage.

Despite the EOBD test procedure, an opacity smoke meter in a service shop will always be required.
As part of an EOBD test, vehicles must pass a readiness test. This is an internal test in the microprocessor of a vehicle. The result of the test is a digital ‘Yes’ or ‘No’. If this test is not passed, a classical smoke emission test with an opacity meter must be performed. In other words, every roadworthiness service shop will still need an opacity meter, which can also be used for detailed DPF investigations.

A smoke emission test procedure for vehicles with DPF must consist of a predefined sequence.
The results of the five different tests clearly show the vehicle’s history affects the smoke emission test results. This history must be removed by a certain pre-conditioning of the roadworthiness test. This removal of the history is part of the test procedure. Based on the test results of this project, the next test sequence is suggested:

1. Visual inspection of the DPF.
2. Manual inspection of the tail pipe with a white tissue.
3. EOBD test.
4. 1-10 free acceleration tests with opacity meter until results are stable.
5. Apply a limit value for the opacity that fails vehicles with removed or damaged filters, but prevents unjustified rejection.

6 Conclusions

Investigations for development of a new roadworthiness smoke test procedure of light duty diesel vehicles with Diesel Particulate Filters were performed with 400 vehicles. In order to assess the functionality of the DPF's every vehicle was subjected to five different tests.

The smoke emission tests result in the following conclusions for roadworthiness testing of Euro 5 diesel engines with diesel particulate filters (DPF):

- In roadworthiness tests with 355 diesel vehicles equipped with a DPF, at least 21 vehicles (6%) showed elevated smoke emissions. This indicates that these 21 Diesel Particulate Filters are either damaged or removed. The EOBD test results of these vehicles however passed all criteria, which indicates that EOBD tests are until now not suitable to detect failures of Diesel Particulate Filters, either because they are simply not capable of doing so, or because the software has been deliberately manipulated in order to prevent detection. Probably the percentage of damaged or removed DPF's in the Dutch vehicle fleet is higher because measuring data of some tested vehicles are not complete and vehicles owners attended in this project on a voluntary basis.

- The free acceleration smoke emission test with an opacity meter is a good means to detect malfunctioning or removed DPF's. In order to stabilise the test results, pre-conditioning of the exhaust is however needed. This can be done by performing several free acceleration tests.

- If a roadworthiness test procedure consists of several different tests, the test sequence of the different tests must be specified. The sequence should be such that it eliminates history effects of the exhaust systems.

- For roadworthiness purposes, free acceleration smoke emission tests with white tissues are complex and time consuming, and do not have an additional value over the opacity test.

- The current test data of smoke emission tests of 21 vehicles are suspicious and cause some concerns. It seems that at least 6% of the diesel light duty vehicles run with increased PM emissions. These elevated PM emissions may influence the national emission factors and hence endanger meeting air quality standards for PM10 and PM2,5. But even when air quality standards are not exceeded, additional emissions of particulates has a negative effect on public health.

7 Recommendations

In this research project a smoke emission limit value of 0.50 1/m has been chosen. If the test result exceeds this value the vehicle has a ‘fail’. In case of implementation of a new smoke emission test procedure this limit value must further evaluated. This will probably result in less dishonest fail or pass test results. Further practical research with more vehicles is recommended.

8 References

[1] Kadijk, Roadworthiness Test Investigations of Diesel Particulate Filters, TNO report 2013 R10160

9 Signature

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Jordy Spreen
Projectleader

TNO

Gerrit Kadijk
Author