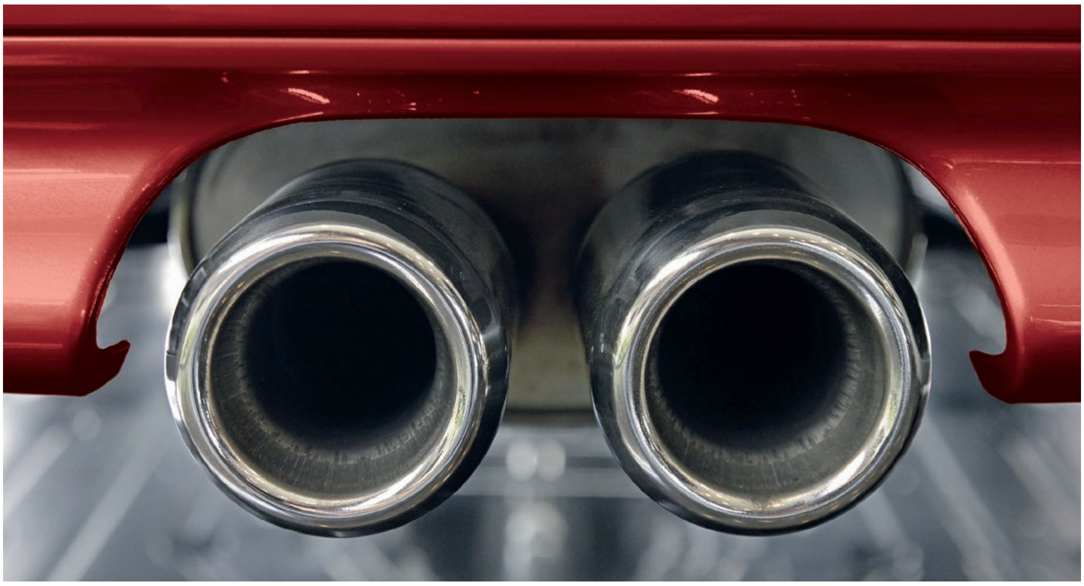
DIESEL PARTICULATE FILTERS FOR LIGHT-DUTY VEHICLES: OPERATION, MAINTENANCE, REPAIR, AND INSPECTION



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TNO innovation for life

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TNO REPORT

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SUMMARY

Combustion of diesel fuel in a vehicle's engine produces particulates, which are often referred to as 'particulate matter' or 'PM'. These particulates are emitted to the environment through the exhaust. Particulates have a negative impact on human health, because they enter the human body through the lungs.

To reduce the emission of particulates from diesel cars and vans, late model vehicles in these categories have been fitted with a diesel particulate filter (DPF). Particulate filters are very effective: a properly functioning filter reduces particulate emissions from light-duty diesel vehicles by 95 to 99%.

A particulate filter can, however, fail or become blocked. The filter must then be cleaned or replaced. Replacement of a DPF, in particular, can be very expensive. Vehicle owners therefore sometimes choose to have the filter removed. Removal of a DPF is also offered as part of 'chip tuning' of vehicles.

In the current APK (Dutch periodic motor vehicle inspection) the emissions of late model diesel vehicles with a particulate filter are tested by reading out fault codes from the on-board diagnostics (OBD) system. For old diesels a smoke measurement test must be performed. Only vehicles with extremely high emissions are rejected on the basis of this decades-old smoke test.

When a DPF is physically removed, the DPF software routines are also removed from the vehicle's engine management system. As such, a removed DPF goes unnoticed during the OBD fault code check. Consequently, in the current APK it is not possible to determine whether a DPF has been removed.

Because a DPF reduces the particulate emission from a diesel vehicle by a factor of 20 to 50, removal of the DPF has a strongly negative impact on environmental air quality. It is therefore important to ensure that DPFs remain installed throughout the service life of the vehicle and that they continue to function properly.

Checking for a removed DPF during the APK is only possible if stricter requirements are implemented and a new, more accurate test method is introduced. In 2016, TNO therefore conducted an exploratory study commissioned by the Dutch Ministry of Infrastructure and the Environment to examine ways of checking whether a properly functioning DPF is present as part of the APK in the future.

The study found two measurement methods to be suitable as a new APK DPF test: (1) a smoke (or opacity) measurement conducted with a more accurate opacimeter with stricter requirements for the smoke emissions, and (2) measurement of the number of particles in the exhaust gas using a particle counter.

The particle counter provides the best results. This type of meter has a significantly better distinguishing ability than the improved smoke meter. Moreover, a measurement with a particle counter can be performed at idle speed. The sampling hose of the particle counter is placed in the vehicle's tailpipe for a short time. This makes this method very fast. Because the measurement of the number of particles does not have to be carried out during free acceleration of the engine, this method is less demanding for the car's engine and places a smaller burden on the inspector.

Opacimeters have become more accurate with the years. However, particularly when it comes to modern diesel engines, measurements with this equipment are made at the lower end of the measuring range. Another aspect is that with this measurement method the dynamic response to a certain level of particulate emissions at free acceleration is inadequately defined, due to factors such as filtering of the data. For the purpose of the APK, this makes opacimeters less suitable than particle counters for determining whether a DPF has been removed. The price of opacimeters is, however, lower than the current price of particle counters.

To ensure that the APK of the future is suitable for inspection of vehicles with a DPF it is important that an improved method of checking a vehicle's particulate emissions is introduced in the APK. Which measurement method will be used depends to an important extent on the costs for automotive repair businesses and inspection stations.

TNO advises the Ministry to further investigate both measurement methods, the possibilities for further development, and the price thereof in close collaboration with the Netherlands vehicle registration authority (RDW) and suppliers of the measurement equipment. It is also important to ensure that there are good calibration methods so the equipment can be calibrated on-site at the automotive repair businesses and inspection stations.

1 INTRODUCTION

BACKGROUND

The combustion of diesel fuel in a vehicle's engine produces particulates, which are often referred to as 'particulate matter' or 'PM'. These particulates are emitted to the environment through the exhaust. Particulates have a negative impact on human health, because they enter the human body through the lungs. To reduce the emission of particulates from diesel vehicles, light-duty diesel vehicles have been fitted with a diesel particulate filter since about 2007. A diesel particulate filter is often referred to with its abbreviation only: 'DPF.'

Figure 1. A particulate filter for a passenger car, as part of the exhaust system. The filter element (see figure 2) is located in the metal canister (photo: Topcats).

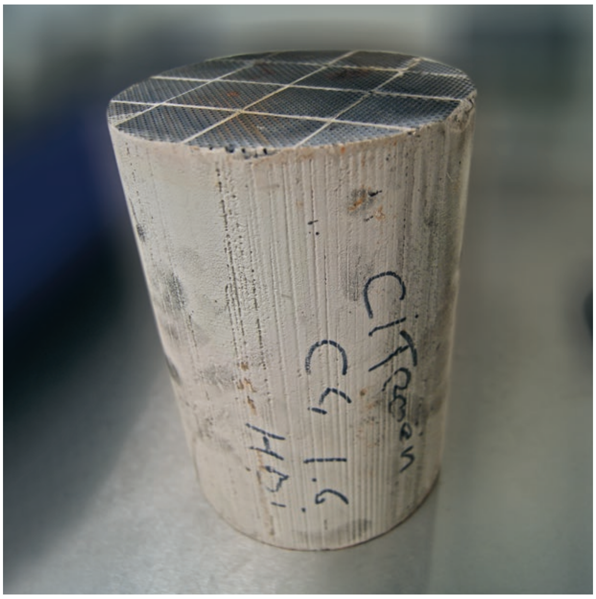

Figure 2. An extracted wall-flow filter element, in this case from a Citroen C4. This DPF has an approximate diameter of 10 cm and is about 20 cm long (photo: TNO at Digicar Engineering).

DPFs are very effective. A properly functioning DPF reduces particulate emissions from diesel passenger cars by 95 to 99%. The effect of the introduction of DPFs for diesel vehicles is of the same order as the effect of the introduction of the three-way catalytic converter for petrol cars. In the 1980s the three-way catalytic converter led to a significant reduction of emissions of NO_x, CO and hydrocarbons (HC).

A particulate filter can, however, fail or become blocked. There are also reports that, for a variety of reasons, particulate filters are sometimes removed from cars. Various studies have shown that the particulate filter had been removed or was defective in approximately 5 to 7% of diesel passenger cars.[1, 2]

To determine whether vehicles are fitted with a properly functioning DPF throughout their service lives, inspection during the APK (Dutch periodic motor vehicle inspection) seems to be the right approach. In early 2016, TNO conducted an exploratory study commissioned by the Dutch Ministry of Infrastructure and the Environment to examine the possibilities for checking whether a DPF is present and functioning properly as part of the APK.

PURPOSE OF THE REPORT

This publication provides factual information about the operation, application, and maintenance of DPFs. It also examines the possibilities for checking whether a DPF is present and functioning properly as part of the APK.

READING GUIDE

The publication is organised as follows: To begin with, an explanation of the substances a DPF captures is provided in chapter 2. This is followed by an explanation of the operation, maintenance requirements, and typical malfunctions or failures of DPFs, in chapter 3. Chapter 4 shows that the number of diesel vehicles with a DPF has grown in recent years and that, as a result, the particulate emissions from diesel passenger cars and vans have dropped significantly. The resulting environmental benefits can only be maintained if DPFs continue to function properly and remain in place throughout the life of the vehicle. Chapter 5 explains why it is not possible to check whether a DPF is defective or has been removed within the scope of the current APK. Chapter 6 therefore provides information about how the APK can be changed to ensure that the particulate emissions from diesel vehicles with a DPF continue to remain low in the future.

2 WHICH SUBSTANCES DOES A DPF CAPTURE?

A DPF CAPTURES PARTICULATE MATTER IN THE EXHAUST GASES

A diesel particulate filter captures all the *solid* particles that originate in a diesel engine.

The particulates resulting from the combustion of diesel fuel in the engine can be divided into five categories:

1. **Elemental carbon** (EC, solid particles). The PM emission from diesel engines not equipped with a DPF mainly comprises EC. EC is elemental carbon and gives the particles in diesel exhaust gases the characteristic black colour, which is commonly referred to as soot (figure 3).
2. **Organic carbon** (OC), or partially burnt fuel and oil. OC exits the exhaust partly as a gaseous substance and partly as solids. The ratio of gaseous to solid depends on the conditions and technology. Because the diesel oxidation catalyst in late model diesel vehicles largely reduces the OC, the percentage of OC in the exhaust gas from late model diesels is small.
3. **Metals**. These are solid metal particles that originate from the fuel or lubricating oil and/or are the result of wear in the engine.
4. **Sulphur oxides** (SO_x). In the past, fuel also contained sulphur. Sulphur was a source of particulate matter, because it formed sulphates, which partly exited the exhaust system as 'wet particles' (oxides). Nowadays, however, the quantity of sulphur in fuel is very low and the particulate emissions hardly contain any sulphur oxides at all.
5. **Minerals**. Some lubricating oils also contain minerals, which produce grey ash particles during combustion.

From this it follows that diesel particulate filters mainly capture elemental carbon.

Figure 3. Black deposit on a finger after wiping deposits from a diesel exhaust pipe. The black emission produced when burning diesel is popularly referred to as 'soot.' Soot, however, is not a scientific term. A particulate filter captures all solid particles created during the combustion of diesel. Most of it is elemental carbon, referred to as EC (photo: TNO).

PARTICULATES, PARTICULATE MATTER, AND PM

The particulates emitted by a diesel vehicle enter the outdoor air. Outdoor air contains all kinds of particulates, in addition to those from vehicle engines. The particles with a size of up to 10 micrometres (one hundredth of a millimetre) are generally referred to as 'particulate matter'. Particulate matter is also often simply referred to as PM.

For air quality, there are various requirements for the concentrations of different particulates in the outdoor air. These requirements are based on the maximum size of the particulates. These include requirements for PM10, PM2.5, and PM0.1 (ultrafine) for particulates with a diameter up to 10, 2.5, and 0.1 micrometres (µm) respectively.

The particulates resulting from the combustion of diesel fuel in a modern diesel engine have a diameter of 10 to 200 nanometres (0.01 and 0.2 µm respectively). Because they are so small, these particles enter the body via the lungs during inhalation. It is in this way that they have a negative impact on human health. As a result of the improved combustion in modern engines, the emitted particulates are becoming increasingly smaller: the fraction of PM2.5 and ultrafine particulates from modern diesel engines without a DPF is greater than that from older engines (without a particulate filter).

OTHER SOURCES OF PARTICULATE MATTER

In addition to the particulate emissions from combustion of fuels, particulates are also created during wear of vehicle brakes and tyres. Emissions that result from wear are usually referred to as wear emissions. Wear emissions are not reduced by the particulate filter.

Moreover, particulate matter is not only emitted by vehicles; livestock farms, homes, and industry are also important sources of particulate pollution. Particulate matter is also found in nature, in the form of sea salt and sand for example.

3 WHAT IS A DIESEL PARTICULATE FILTER AND HOW DOES IT WORK?

This chapter discusses the operation of DPFs, the regeneration process – which is an important aspect for the proper operation of a DPF – and the need for maintenance and possible DPF defects.

HOW A DPF WORKS

A DPF is placed downstream of the engine, in the exhaust system (figure 2), and captures the particles there. The exhaust gases and particulates flow through the exhaust system to the filter. The filter allows the gases to pass but captures the particulates.

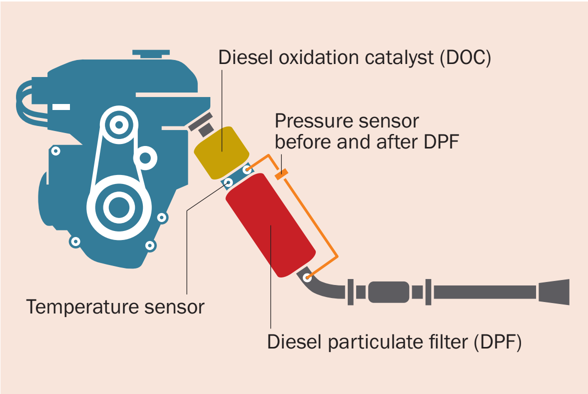

Figure 4. The DPF is located downstream of the engine. In most cases, vehicles with a DPF are also fitted with an oxidation catalyst, which is located upstream of the DPF.

There are two types of DPF: the wall-flow type and the partial or flow-through type. This publication focuses mainly on wall-flow DPFs, because all new light-duty diesel vehicles are fitted with this type.

WALL-FLOW DIESEL PARTICULATE FILTERS

Wall-flow DPFs consist of porous ceramic material containing channels that are all sealed at one end (figures 5 and 6). As a result, all the exhaust gases flow through the porous filter walls. This is why this type is referred to as a ‘wall-flow’ filter. The particulates are stopped at the walls by the pores of the filter material. Because all the exhaust gases are filtered, wall-flow DPFs are very effective; their efficiency is 99% or higher. As captured particles accumulate, they gradually restrict flow through the filter. Therefore the particulate matter collected in a wall-flow DPF must be periodically burned off. This regular burning of the particulate matter, which is called active regeneration, requires the control of the engine management system (see sidebar on page 8). Because making changes to an existing engine management system is very complex, a wall-flow DPF can generally only be installed in a vehicle during the manufacturing process at the factory.

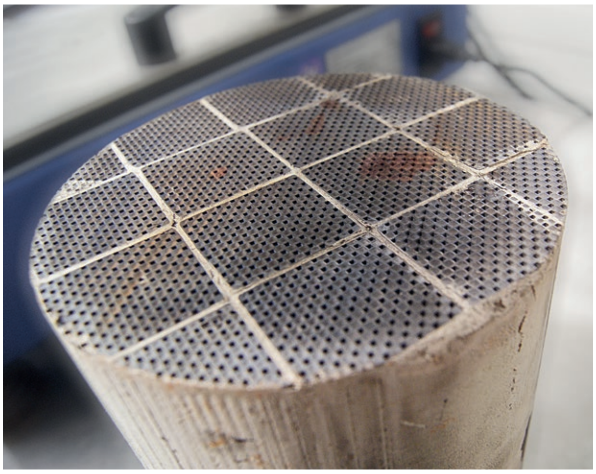

Figure 5. Magnified image of the DPF shown in figure 2: the channels can be seen clearly (photo: TNO).

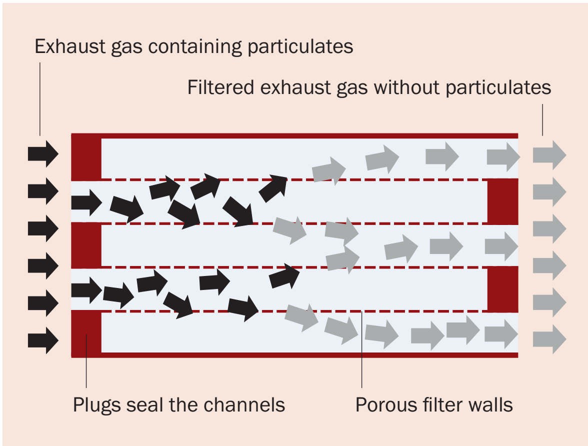

Figure 6. The schematic drawing shows that a DPF is made up of many sealed channels. Because there is a plug at the end of each channel, the exhaust gases can only exit through the filter walls. The particulates ‘get stuck’ in the filter wall.

In most cases, cars with a wall-flow DPF are also fitted with an oxidation catalyst that converts NO to NO_2. This is located upstream of the DPF. NO_2, which is very reactive, causes PM to burn at lower temperatures (250-300 °C). This relatively slow process is called passive regeneration.

For some types of DPF a chemical additive is used. This additive allows regeneration to occur at lower temperatures (about 450 °C). The additive for this type of DPF must be refilled during scheduled maintenance.

PARTIAL OR FLOW-THROUGH DIESEL PARTICULATE FILTERS

The partial or flow-through DPF always allows part of the exhaust gas to pass through without filtration. Therefore the effectiveness of a partial or flow-through DPF, at around 30%, is considerably lower than that of a wall-flow DPF. Because a large fraction of the exhaust gas can flow through the filter unchecked, a partial or flow-through filter cannot become blocked. Systems equipped with partial or half-open filters only make use of passive regeneration. Because active regeneration is never used, control by the engine management system is therefore also unnecessary. This makes it possible to install a partial or flow-through DPF in an existing vehicle. In 2008 and 2009 the Dutch Government made subsidies available for the installation of partial and half-open DPFs in light-duty vehicles.

MAINTENANCE AND DEFECTS

During normal use a wall-flow DPF gradually becomes restricted with ash. When this happens it is often possible to clean the filter. Malfunctions and defects related to the DPF occasionally also occur. In some cases the only option is to replace the filter. This chapter discusses these aspects.

SATURATION OF THE FILTER

During the combustion of particulates a relatively tiny amount of ash is left behind in the DPF. Ash consists mainly of metals that come from the lubricating oil. During use of the vehicle a DPF therefore becomes increasingly contaminated with ash. Because ash cannot be burned the DPF eventually becomes saturated. When this happens, it is also no longer possible to unclog the filter through regeneration. It is for this reason that low-ash engine oil is often prescribed for cars with a DPF. Under normal use of the diesel vehicle a DPF has a service life of 150,000 to 250,000 km. A vehicle with a DPF that is nearly or completely blocked usually provides a notification on the dashboard. When this happens a warning lamp will be lit, which is a recommendation to the driver to visit the garage. It is important that this recommendation is followed; continuing to drive with a restricted DPF can cause irreparable damage to the DPF and even serious engine damage. In the case of a nearly blocked DPF the vehicle owner has two options: clean or replace the filter.

ACTIVE REGENERATION

When the exhaust gases are hot enough, which means hotter than 550 °C, and sufficient oxygen is present, the soot that has accumulated in the DPF burns spontaneously. During daily use, however, the exhaust gases are often not hot enough to burn off the accumulated soot. The DPF then becomes more and more contaminated with soot. Because exhaust gases cannot flow through a blocked filter, that soot must be burned off. This is done through a process called active regeneration. During active regeneration, additional fuel is injected into the exhaust gas, which ignites in the oxidation catalyst of the DPF. This raises the temperature of the exhaust gas to approximately 550 °C, burning the particulates in the DPF to CO_2 and a very small amount of ash.

The regeneration process is controlled by the vehicle's engine management system, which determines whether a regeneration cycle must be carried out based on factors which include the temperature and back pressure in the exhaust system. For proper operation of the engine and the DPF, successful regeneration cycles are of great importance. How often the vehicle regenerates strongly depends on how the vehicle is used. Many short drives in the city are generally unfavourable. The trapped soot is then not burned spontaneously, and in these circumstances an active regeneration often cannot be fully completed. When a vehicle is driven longer distances at higher, motorway speeds, the chance is great that some of the soot will burn spontaneously through passive regeneration. This type of driving also gives the engine management system the opportunity to perform a full active regeneration. In practice, passive regenerations alone are not enough to keep the filter clean.

Active regenerations usually take place every 600 to 1,000 kilometres. At that point approximately 10 to 20 grams of soot has accumulated in the DPF. Because extra fuel is injected during active regeneration, the fuel consumption is temporarily slightly higher. On average, approximately 0.3 to 0.5 litre of diesel is required per active regeneration cycle. Under ideal conditions regeneration takes about 5 to 10 minutes to complete.

Figure 7. An irreparably damaged diesel particulate filter. Continuing to drive with a restricted particulate filter can cause irreparable damage to the DPF and even serious engine damage (photo: TNO at Digicar Engineering).

CLEANING THE FILTER

If the filter is in good condition, cleaning can be attempted. Generally speaking, there are two ways of doing this: (1) using cleaning fluids or fuel additives, or (2) by blowing or spraying out the filter and/or cleaning it in a kiln.

WITH CLEANING FLUIDS OR FUEL ADDITIVES

When cleaning the DPF using fuel additives a solution is added to the fuel that reduces the temperature required for regeneration. The filter can also be cleaned by injecting cleaning fluids into the intake manifold and then running the engine at a higher speed. Cleaning that involves the use of cleaning fluids often involves a forced regeneration.

An advantage of these methods is that the DPF does not have to be removed, and such methods are sometimes also used as a preventive measure. However, they are not always successful, in which case removal will nevertheless be necessary. In some cases these fluids and additives can accumulate in the filter, after which they form a hard layer or lump that can no longer be removed from the filter.

BLOWING OUT, SPRAYING OUT, AND/OR KILN CLEANING

DPFs can also be sprayed out with a pressure washer or blown out using equipment specially designed for this purpose. This results in soot and ash being blown out of the DPF.

Figure 8. A kiln cleaning involves placing a DPF in a kiln for several hours (above). After removal from the kiln the ash is blown out of the filter (bottom) (photo: TNO at Digicar Engineering).

However, the DPF must be removed to do this, and the metal housing of the filter element must be partly removed. Blowing out and spraying out can, as a rule, be performed within a day, so a DPF cleaning can be performed during regular maintenance of the vehicle. If the spraying out or blowing out has insufficient effect, a DPF can be cleaned in a kiln. Heating the filter to a high temperature for several hours burns off any remaining soot. After kiln cleaning the filter is also blown out or sprayed out to remove the accumulated ash. Then the filter is tested by measuring the back pressure and the depth of the channels, and a determination can be made of whether the filter is functioning properly. If so, the filter can be reinstalled. If the filter is still not restored to proper operation, it may be necessary to take the decision to install a new filter after all.

COST AND EFFECTIVENESS OF DPF CLEANING
A cleaned DPF can be used for approximately 100,000 km of driving. Then the filter must generally be cleaned again. The cost of cleaning a DPF ranges from 300 to 400 euros.

DPF-RELATED MALFUNCTIONS

In addition to eventual blockage of a DPF – a normal aspect of use of a filter – in some cases DPF malfunctions also occur. This happens, for example, if regenerations are interrupted before completion numerous times. In such cases a garage can perform a forced regeneration, after which, under normal circumstances, the DPF functions again.

DPF DEFECTS

A DPF can also become defective. Cracks can develop in the filter element for a variety of reasons, but often particularly as a result of excessive regeneration. This causes the filter to ‘leak’ internally, allowing some of the exhaust gas to flow through without filtration. This reduces the effectiveness of the filter. Defective DPFs cannot be repaired; in such cases replacement is the only option.

Whenever a DPF malfunctions or fails it is advisable to investigate the cause. The cause is not always just a restricted DPF or a failed regeneration: a clogged air filter, excessive engine oil consumption, a faulty injector, a faulty turbo or, for example, faulty sensors can lead to the accelerated blockage of the DPF. If these problems are not resolved, a cleaned or new DPF will probably become restricted more quickly than usual.

COST OF DIESEL PARTICULATE FILTER REPLACEMENT

Replacement of a DPF is very costly. Prices range from slightly less than 1,000 to 4,000 euros, excluding installation.

GOOD CONSUMER ADVICE IS VERY IMPORTANT

From the information above it is clear that it is important to provide consumers with good advice when buying a diesel vehicle equipped with a DPF. This is particularly important because under certain circumstances the DPF requires additional attention. For those who drive relatively few kilometres and often short distances, a vehicle with a diesel engine and DPF is generally not a good option, because the conditions required for regeneration of the DPF are not achieved.

4 DIESEL PARTICULATE FILTERS IN THE NETHERLANDS

Since the introduction of the Euro 5 emission limits in 2010-2011, all new light-duty diesel vehicles have been fitted with a DPF. Thus new diesels that have been sold since that time have such a filter. This chapter shows how many light-duty diesel vehicles, i.e. cars and vans, in the Netherlands were equipped with a DPF on 1 January 2016 and what effect that has on their particulate emissions.

THE NUMBER OF VEHICLES WITH DIESEL PARTICULATE FILTERS IN THE NETHERLANDS

On the reference date, 1 January 2016, there were 8.4 million passenger cars registered with the RDW (the Dutch vehicle registration authority) in the Netherlands. 1.4 million passenger cars run on diesel, of which 59% are fitted with a DPF. In addition to the new models that come with a factory-installed DPF (57%), there are also older vehicles on the road that have a retrofit DPF (2.3%). Figure 9 clearly shows that the Euro 5 standard went into force in 2010/2011: after that time there are no new registrations of passenger cars equipped with a diesel engine without a DPF.

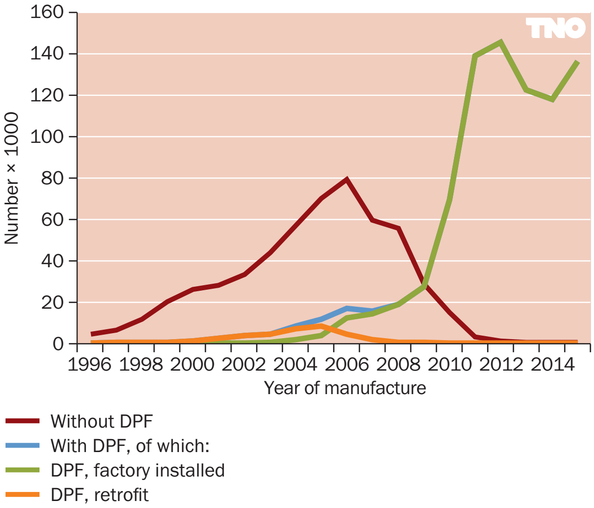

Figure 9. Number of diesel passenger cars per year of manufacture registered in the Netherlands on 1 January 2016.

Of the 910,000 light commercial vehicles (vans) in the Netherlands, 95% run on diesel. Of these diesels, 37% have a DPF, of which, once again, most are factory installed (36%) and a small fraction are retrofit (1%). Figure 10 shows the year of manufacture of the diesel light commercial vehicles currently registered in the Netherlands. The sale of new vans without factory-installed DPF was completely ended in 2014. However, vehicles without a DPF are still being imported. During the past nine years the number has been around 1,000 imported vehicles per quarter.

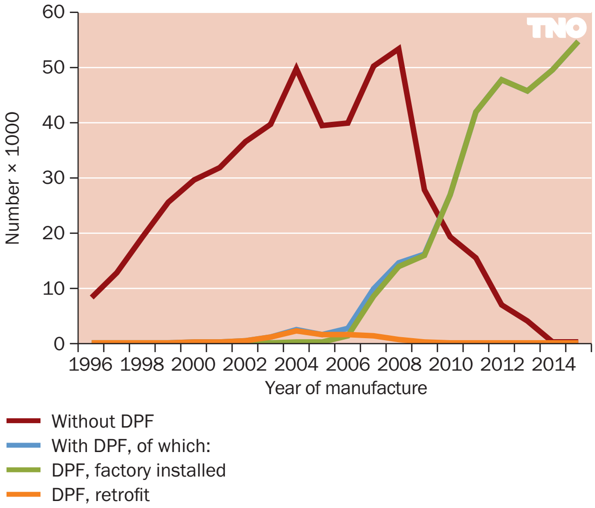

Figure 10. Number of diesel light commercial vehicles per year of manufacture registered in the Netherlands on 1 January 2016.

DIESEL PARTICULATE FILTERS RESULT IN LOW PARTICULATE EMISSIONS

The following figures show that DPFs result in significant reduction of the particulate emissions from diesel vehicles. Figures 11 and 12 show that the particulate emissions from light-duty diesel vehicles in the city – where these vehicles have a considerable impact on environmental air quality – have significantly declined over the years. The strict limit for emissions of particulate matter in the Euro 5 standard, which came into force in 2010-2011, has meant that car manufacturers could only comply with the legal requirements by equipping vehicles with wall-flow DPFs as original equipment. The actual PM emissions following introduction of the Euro 5 standard are hardly measurable and can therefore hardly be noticed in the figure.

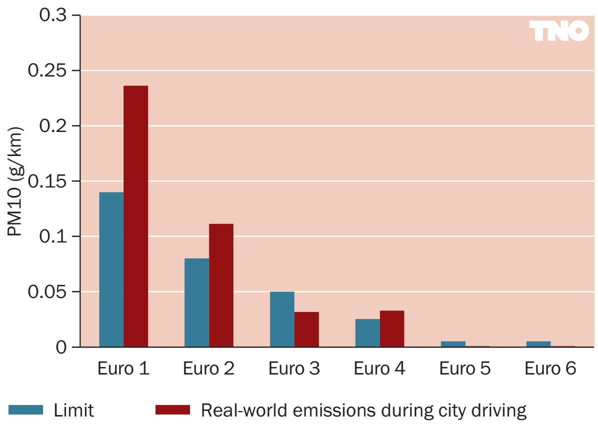

Figure 11. The Euro 5 and 6 emission limits for PM can only be met by equipping diesel vehicles with a DPF as original equipment. The effectiveness of the DPF is clearly shown by this figure with real-world emissions during city driving. Since Euro 5, PM emissions from passenger cars have decreased sharply. The real-world emissions from Euro 5 and 6 vehicles are well below the standard and barely measurable.

Diesel light commercial vehicles show the same trend (figure 11). DPFs as original equipment on Euro 5 diesel light commercial vehicles were introduced in around 2010.

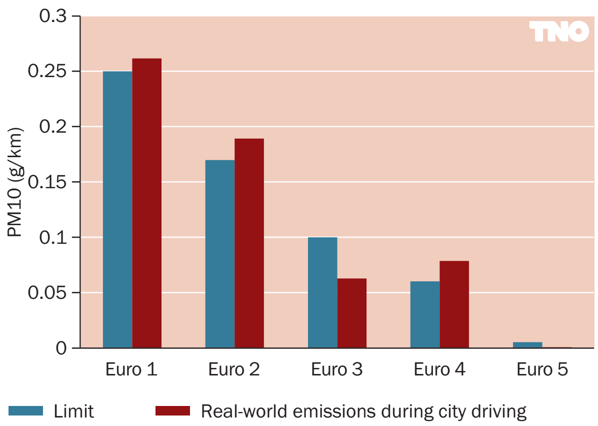

Figure 12. The PM emissions from light commercial vehicles have also decreased considerably in recent decades. Euro 5 light commercial vehicles are equipped with a wall-flow DPF and have very low particulate emissions. The real-world emissions from these vehicles are well below the standard and barely measurable.

With the introduction of the Euro VI standard for heavy-duty vehicles in 2014, wall-flow particulate filters have also become standard equipment on lorries, buses, and coaches with a diesel engine.

5 THE DIESEL PARTICULATE FILTER IN THE APK

In some cases DPFs are removed. This chapter describes why and how this happens and what the consequences are. Also explained is why it is not possible to check for the presence and proper operation of the DPF within the scope of the current APK.

THE REMOVAL OF DIESEL PARTICULATE FILTERS

WHY ARE DIESEL PARTICULATE FILTERS SOMETIMES REMOVED?

As a result of normal wear of the diesel engine, the amount of particulate matter a vehicle emits gradually increases throughout its service life. This increasing quantity of PM emissions is captured by the DPF. As the vehicle mileage increases, the DPF will become restricted more quickly and will therefore have to be regenerated more frequently. This increases the likelihood of malfunctions and/or failure of the DPF.

As described earlier, in some cases replacement of a DPF can be very expensive, certainly for the private vehicle owner. While cleaning a blocked filter is less expensive than replacement, even this can be seen by some as a prohibitively expensive procedure, and it must also be repeated approximately every 100,000 km thereafter. It is known that in both cases vehicle owners sometimes choose to have the filter removed.

The removal of a DPF is also offered as part of ‘chip tuning’ of vehicles. This tuning aims to achieve better engine performance and somewhat improved fuel economy. Occasionally, along with elimination of the DPF, the exhaust gas recirculation (EGR) system is also deactivated or removed as part of chip tuning.

WHAT DOES ELIMINATION OF A DIESEL PARTICULATE FILTER INVOLVE?

When a DPF is eliminated, the DPF is disassembled and the filter element is removed from the housing. In some cases a dummy filter is installed, after which the housing is welded back together. The DPF software routines are also eliminated from the vehicle’s engine management system. This is done to prevent fault codes from occurring in the on-board diagnostics (OBD) system. As a result, no ‘undesirable’ warning lamps light on the dashboard and the eliminated DPF goes unnoticed during the APK.

WHY IS REMOVAL OF A PARTICULATE FILTER A PROBLEM?

As the figures in the previous chapter showed, DPFs play an important role in reducing PM emissions from diesel vehicles. They reduce the PM emissions of the vehicle by a factor of 20 to 50. Especially in the city, where there are still many diesel vehicles on the roads, this has a major positive effect on air quality. To maintain this positive environmental impact it is therefore important to ensure that DPFs remain installed throughout the service life of the vehicle and that they continue to function properly.

METHOD FOR MONITORING PARTICULATE EMISSIONS USED IN APK IS OUTDATED

In the Netherlands, the APK (periodic motor vehicle inspection) verifies that a vehicle meets the technical requirements of the Dutch vehicle regulations (‘Regelingen Voertuigen’). For diesel vehicles, the first inspection takes place three years after initial vehicle registration and annually thereafter. The APK for a diesel vehicle includes a check to ensure that the vehicle smoke emissions are within the limit. For late model diesel vehicles this is primarily done by checking the vehicle’s on-board diagnostics (OBD) system: it must not report any emission-related faults. If this test cannot be performed or if there are fault codes, a smoke measurement must be performed.

SMOKE MEASUREMENT IN THE CURRENT APK

The smoke measurement in the APK consists of determining the smoke emission from the vehicle using a smoke meter, which measures the absorption coefficient (or opacity) of the exhaust gases (figure 13). This absorption coefficient (referred to as ‘parameter k’) is a value for the smoke emission of the vehicle and can range from 0 to 10 m^{-1}. The more particles (EC) the vehicle emits, the dirtier (blacker) the exhaust gases and the higher the absorption coefficient. The PM measurement is carried out ‘at free acceleration’: the maximum smoke emission is measured while the throttle pedal is depressed fully.

Figure 13. The PM emissions from diesel vehicles can be determined during the APK using a smoke meter. For late model diesel vehicles, however, it is permitted to simply check the OBD system for fault codes (photo: TNO).

The Dutch vehicle regulations specify limit values for the smoke emission of diesel vehicles (table 1). For light-duty vehicles with a diesel engine the emission levels may not exceed the absorption coefficient values shown in the table. If the national vehicle register (BRV) lists a higher extinction coefficient value for a vehicle than shown in the table, this higher value may be used for the inspection.

Table 1. Absorption coefficient limit values for the exhaust gases from diesel engines. If the national vehicle register (BRV) lists a higher absorption coefficient value for a vehicle than shown in the table, this higher value may be used for the inspection.

Vehicle type	Initial registration voertuig	Absortion coefficient (parameter k) (m^{-1})
Turbocharged engine	After 31 December 1979 and before 1 July 2008	3.0
Naturally aspirated engine	After 31 December 1979 and before 1 July 2008	2.5
All diesel engines	After 30 June 2008	1.5

The current smoke measurement method is an optical measurement with limited accuracy and is already several decades old. In the early days, manufacturing discrepancies in diesel engines were such that there was a certain amount of variability in the smoke emission even from new engines. The limit value for the smoke emission from diesel vehicles is therefore based on smoke emission measured in the type approval, with an additional margin of 0.5 m^{-1} to accommodate this variability. This method, with corresponding limit value, is still used for the type approval in 2016 and is utterly dated. To illustrate this: modern diesel engines with a DPF have a smoke emission level of around 0.03 m^{-1}. Furthermore, the smoke emission level from modern diesel engines without a DPF is typically already below 0.5 m^{-1}.

ON-BOARD DIAGNOSTICS (OBD) CHECK FOR EMISSION-RELATED MALFUNCTIONS

Late model diesel vehicles with a properly functioning DPF achieve an extinction coefficient of 0.01 to 0.03 m^{-1}. These values cannot be measured with the exhaust emission testing equipment currently in use for the APK; the equipment is simply not accurate enough. Older diesel vehicles (Euro 4 and older) are subject to a mandatory free acceleration smoke test.

Because of the low smoke values from diesel vehicles with a DPF, reading out the on-board diagnostics system (OBD) is an acceptable alternative for passenger cars initially registered after 31 December 2005 (Euro 5 and Euro 6) fitted with such a system. According to the Dutch vehicle regulations, the OBD system may not have any emission-related fault codes and the vehicle must have a properly functioning warning mechanism which informs the driver in the event of a malfunction of an emission control system such as the DPF.

The Dutch vehicle regulations prescribe that the correct operation of the warning system must be established and gives instructions for the way in which the OBD system must be read out.

If the readout is successful and the OBD system reports no emission-related faults, the vehicle passes this part of the inspection. If emission-related faults are found, the vehicle is subjected to a smoke measurement test. The measured smoke values from the vehicle may not exceed those shown in table 1.

REMOVED DIESEL PARTICULATE FILTERS AND THE APK

Because during physical removal of the DPF the vehicle's software is also modified, the current APK cannot determine whether a DPF has been removed. This is not possible with the current smoke test either, because it is not accurate enough.

Checking for the presence of a DPF during the APK is difficult, because no parts may be removed during the APK inspection. An inspector may inspect the housing of the DPF for repair welds and knock on the housing to assess whether the housing is empty or filled. If the housing seems to be filled, however, there is no way to determine with certainty whether the housing is filled with a particulate filter or a dummy.

In the event that the OBD readout fails and the vehicle must therefore undergo a smoke test, chances are that a modern Euro 5 or Euro 6 vehicle will pass this smoke test even with the DPF removed. Many Euro 5 or 6 vehicles without a DPF have an absorption coefficient of well below 0.5 m^{-1}. The limit value for vehicles initially registered after 30 June 2008, at 1.5 m^{-1}, is so high that late model vehicles with a defective or removed DPF will simply be approved in the current APK.

6 AN APK DIESEL PARTICULATE FILTER TEST

DPFs are important for good air quality. It is therefore important to be able to establish the presence and proper operation of a DPF in daily practice. Such control can take place during an APK. With the current APK, however, it is not possible to determine whether a late model diesel vehicle is fitted with a properly functioning DPF. Checking for removed and defective DPF is only possible if the APK requirements are made stricter and a new test method is prescribed.

PREVIOUS STUDIES

In recent years various studies have been conducted on the performance of DPFs and the possibilities for checking for their presence and proper operation. Previous studies conducted by TNO and a major study by the International Motor Vehicle Inspection Committee are discussed briefly in this section.

TNO STUDIES ON PERFORMANCE OF DIESEL PARTICULATE FILTERS AND VERIFICATION THEREOF

During an initial study carried out for the Dutch Ministry of Infrastructure and the Environment in 2013, TNO investigated test methods and procedures for the assessment of wall-flow DPFs involving the use of various types of smoke meters.[3] The results of this study showed that the current free acceleration test with a state-of-the-art, improved opacimeter may be suitable for use in the APK test for vehicles with a wall-flow DPF.

At the request of TNO, in 2015 the RDW conducted additional testing on approximately 400 vehicles that were selected for APK random verification testing.[4] The main purpose was to obtain an indication of the percentage of vehicles with a defective or removed DPF. This study showed that the DPF had been removed or was defective in approximately 5 to 7% of the light-duty diesel vehicles with factory-installed particulate filter.

STUDY BY THE INTERNATIONAL MOTOR VEHICLE INSPECTION COMMITTEE

As part of the Sustainable Emission Testing (SET) project, the International Motor Vehicle Inspection Committee (CITA) conducted smoke emission tests on a total of 1654 diesel vehicles.[3] The OBD system was also read out, if present. Of the tested light-duty diesel vehicles, 469 were factory equipped with a wall-flow DPF.

The measurements were performed during motor vehicle roadworthiness inspections in seven European countries. The CITA study found no link between vehicles that fail on the basis of the OBD readout and vehicles that fail based on the smoke emission test. Therefore the study made the recommendation that both an OBD readout and a smoke emission test be included in motor vehicle roadworthiness inspections.

The SET study concludes that the current absorption coefficient limits established in European Directive 2010/48/EC are too high to effectively test Euro 5 vehicles and recommends an extinction coefficient of 0.20 m^{-1} for the future.

STUDY TO FIND A NEW APK TEST METHOD

In 2016, TNO conducted a study commissioned by the Dutch Ministry of Infrastructure and the Environment to examine ways of checking for the presence and proper operation of DPFs.[4]

SCOPE OF THE STUDY

The study not only looked at changes to the method currently in use – a measurement based on imperviousness to light (or opacity) – but also examined new methods of measurement and limit values. For 213 diesel vehicles, TNO measured the absorption coefficient values with two different types of smoke meters. In addition, the number of particles in the vehicles' exhaust gas was measured using a particle counter. The study found two suitable options for an APK DPF test.

TWO SUITABLE OPTIONS FOR AN APK DIESEL PARTICULATE FILTER TEST

A SMOKE MEASUREMENT WITH A MODERN, IMPROVED SMOKE METER

In the study a smoke measurement was performed with a state-of-the-art, 'improved' smoke meter (or opacimeter), with greater sensitivity than the old meters. For reference, all 213 vehicles were also measured with a conventional, 'standard' smoke meter of the type currently used for the APK (figure 14).

The study confirms that the smoke meter currently used for the APK is not suitable for determining whether the DPF is present or is functioning properly. The meter is too imprecise

Figure 14. In the 2016 study, the absorption coefficient values were measured with two types of smoke meter: a conventional or 'standard' smoke meter (or opacimeter) as is currently used for the APK (right), and a state-of-the-art, 'improved' smoke meter (or opacimeter) (left) with greater sensitivity than the old meters. A smoke measurement is carried out 'at free acceleration': the maximum smoke emission is measured while the throttle pedal is depressed fully (photo: TNO).

and lacks the sensitivity to measure the low PM emissions from late model, Euro 5 and 6 diesel vehicles. When the state-of-the-art smoke meter reports low absorption coefficient values of between 0.01 and 0.05 m^{-1}, the measurement result with the current smoke meter is often zero.

With its greater sensitivity than the standard opacimeter, the state-of-the-art opacimeter is more capable of distinguishing between a vehicle with a properly functioning DPF and one in which the DPF is defective or has been removed, even for the low smoke emissions of modern diesel engines. It should be noted here that even with the improved smoke meter the measurements are still always at the bottom end of the range, making the discriminative ability of this meter lower than that of the particle counter (see next section). Another aspect of this measurement method is that the static calibration of the smoke meter is not in keeping with the dynamic nature of the measurement. More insight is also needed into the filtering of the electronic measurement signals employed in the smoke meters, which is an important aspect in the assessment of smoke emissions. The method of calibrating the meters and the filtering of measurement signals must be discussed with suppliers of smoke meters.

MEASUREMENT OF THE NUMBER OF PARTICLES IN THE EXHAUST GAS WITH A PARTICLE COUNTER

In addition to the conventional smoke measurement, the number of particles (Particle Number or PN) in the exhaust gases of the 213 diesel vehicles was measured using a particle counter (figure 15). The measurement is carried out at idle. This is a measurement method that is not currently used in the APK.

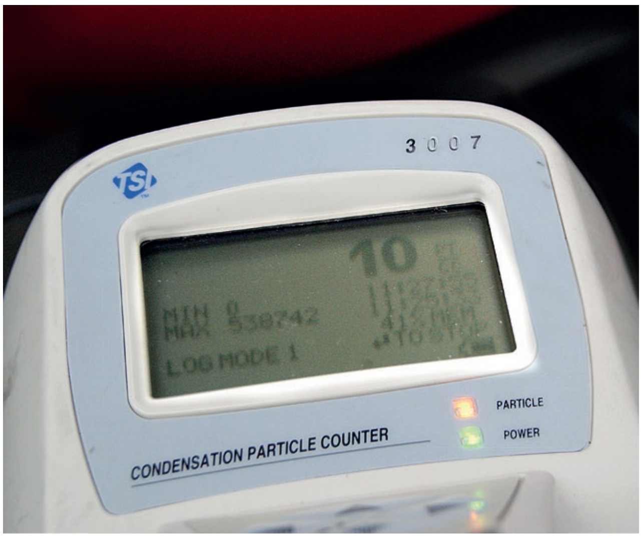

Figure 15. In addition to the conventional smoke measurement, the number of particles (Particle Number of PN) in the exhaust gases of the 213 diesel vehicles was measured using a particle counter. The sampling hose is placed in the exhaust tailpipe while the warm engine runs at idle (left). The device displays the number of particles per cm^3 ('10' in the photo at the right) (photo: TNO).

Compared to an opacity measurement, a particle measurement is very fast, accurate, and user-friendly. From a technical and health point of view, measurement with a particle counter is therefore preferable to measurement with the improved opacimeter. Another advantage is that this measurement is not as easy to manipulate as the opacity measurement.

The device, however, is currently more expensive than a smoke meter, and it should be noted that the equipment used was not specifically designed for use in the APK. In addition, it should be investigated whether a calibration method is necessary and feasible in daily practice to make this suitable for the APK. The particle counter must therefore also be developed further for use in the APK. It is advisable to consult with suppliers to set this further development in motion.

CONCLUSIONS OF THE STUDY

Two measurement methods are suitable for use in the APK to check whether a properly operating DPF is present: the conventional smoke measurement with a state-of-the-art, improved smoke meter and a measurement of the number of particles in the exhaust gas using a particle counter.

Of the two, the particle counter provides the best results. This type of meter has a significantly better distinguishing ability than the improved smoke meter. Moreover, a measurement with a particle counter can be performed at idle speed. This involves placing the sampling hose in the vehicle's tailpipe for a short time. The method is therefore very fast. Because the measurement of the number of particles does not have to be carried out during free acceleration, this measurement method is less demanding for the car and places a smaller burden on the inspector.

Opacimeters have become more accurate with the years. However, particularly when it comes to modern diesel engines, measurements with this equipment are made at the lower end of the measuring range. Another aspect is that with this measurement method the dynamic response to a certain level of particulate emissions at free acceleration is inadequately defined, due to factors such as filtering of the data. For the purpose of the APK, this makes opacimeters less suitable than particle counters for determining whether a DPF has been removed. The price of opacimeters is, however, lower than the current price of particle counters.

RECOMMENDATIONS OF THE STUDY

To ensure that the APK of the future is suitable for inspection of vehicles with a DPF it is important that an improved method of checking a vehicle's particulate emissions is introduced in the APK. Which measurement method will be used depends to an important extent on the costs for automotive repair businesses and inspection stations.

TNO advises the Ministry to further investigate both measurement methods, the possibilities for further development, and the price thereof in close collaboration with the RDW (Netherlands vehicle registration authority) and suppliers of the measurement equipment. It is also important to ensure that there are good calibration methods so the equipment can be calibrated on-site at the automotive repair businesses and inspection stations.

In older diesel vehicles with no filter it is common practice to manipulate the APK smoke test by adding special fluids or petrol to diesel. Today there is also Fischer-Tropsch diesel available, such as GTL, which can reduce the particulate emissions. Further research is needed to determine the effect of these manipulation possibilities on the measurement results of the improved smoke meter and the particle counter.

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