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TNO report

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Follow-up research into the PN limit value and the measurement method for checking particulate filters with a particle number counter

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Samenvatting

Aanleiding
Om de uitstoot van roetdeeltjes terug te dringen, zijn moderne auto's uitgerust met een roetfilter. Roetfilters zijn zeer effectief: een goed werkend filter vermindert de uitstoot van roet met 95 tot 99%.
Roetfilters hebben in 2002 hun intrede gedaan op de Nederlandse markt voor personenauto's met dieselmotor en worden sinds 2007 in Nederland grootschalig toegepast als gevolg van fiscale stimulering. De Europese Euro 5 norm, in het bijzonder vanaf de Euro 5b norm met deeltjesaantallen eis, heeft ertoe geleid dat roetfilters inmiddels worden toegepast op alle nieuwe dieselpersonenauto's (sinds 2010) en dieselbestelwagens (sinds 2011). De Euro VI norm voor vrachtwagens en bussen is vanaf 2013 van kracht en deze voertuigen zijn ook uitgerust met een roetfilter. Sinds 2019 worden roetfilters ook op benzinepersonenauto's toegepast.

Een roetfilter kan verstopt raken of kapot gaan. Het filter moet dan worden gereinigd of vervangen. Met name het vervangen van een roetfilter kan een kostbare zaak zijn. Daarom kiezen autobezitters er soms voor om het filter te laten verwijderen. Eerder uitgevoerde onderzoeken naar het aandeel voertuigen met defecte en/of verwijderde roetfilters zijn een indicatie dat deze groep voertuigen substantieel bijdraagt aan de totale PM10 emissie van dieselvoertuigen die zijn uitgerust met een roetfilter.

Met de huidige APK testprocedure is het niet mogelijk om vast te stellen of een goed werkend roetfilter aanwezig is. Moderne dieselvoertuigen met roetfilter worden op uitstoot gecontroleerd door het uitlezen van het Emissie On-Board-Diagnostics-system (EOBD). Omdat bij het fysieke verwijderen van het roetfilter deze ook wordt 'weggeprogrammeerd' in de software van de auto, wordt een verwijderd roetfilter in de EOBD-controle niet opgemerkt.

Controle op defecte roetfilters in de APK kan alleen als de eisen strenger worden en een nieuwe, meer nauwkeurige testmethode wordt ingevoerd. De wijze waarop nu roetfilters in de APK worden gecontroleerd heeft tot gevolg dat bij een aanzienlijk deel van de dieselauto's het roetfilter wordt verwijderd om onderhoudskosten uit te sparen. Daarnaast worden met de huidige wijze van controle van roetfiltertest in de APK ook defecte roetfilters veelal niet opgemerkt. In beide gevallen heeft dit een negatief effect op luchtkwaliteit.

In 2017 heeft TNO een methode voor een effectieve controle van roetfilters van dieselvoertuigen in de APK [1] voorgesteld door middel van een test bij stationair toerental waarin de deeltjesaantallen (PN)-emissie wordt gemeten. Ook in de typekeuring is gebleken dat een limiet op de PN emissie de robuuste eis is aan een goedwerkend roetfilter. Een PN eis heeft geen directe relatie met de op massa gebaseerde indicator voor de luchtkwaliteit. Dit komt omdat de afmetingen van dieselroetdeeltjes zeer klein zijn (nano-deeltjes) en nauwelijks bijdragen aan de fijnstof massa. Om deze reden wordt bijvoorbeeld een PN limietwaarde niet in Amerika toegepast.

De limietwaarde voor Euro 5b/6 voertuigen, die aan de PN-eis moeten voldoen, zou in een APK-test bij stationair toerentallen kunnen liggen op 250,000 #/cm^3 en voor Euro 3, 4 en 5a voertuigen met roetfilter, zonder PN-eis maar met een deeltjesmassa eis, zal deze kunnen liggen rond 1,000,000 #/cm^3.

Ter verdere onderbouwing van de PN limietwaarden in de APK zijn in dit onderzoek diverse dieselvoertuigen onder APK condities gemeten. Ook zijn ter oriëntatie de PN emissies van een aantal benzinevoertuigen met roetfilter onder APK-condities gemeten. Verder is in dit onderzoek onderzocht of de APK deeltjestest die is ontwikkeld voor dieselmotoren ook geschikt is voor benzinemotoren.

Doel
Het Ministerie van Infrastructuur en Waterstaat heeft TNO verzocht een onderzoek uit te voeren naar passende PN limietwaarden voor een nieuwe deeltjestest waarmee in de toekomst in de APK kan worden gecontroleerd of een goed werkend roetfilter aanwezig is.

Aanpak
In totaal zijn gedurende het onderzoek 51 diesel- en 6 benzinevoertuigen getest. Het ging om 19 dieselvoertuigen zonder roetfilter en 32 dieselvoertuigen met roetfilter, drie benzinevoertuigen zonder roetfilter en drie benzinevoertuigen met roetfilter. De personen- en vrachtwagens zijn gehuurd of beschikbaar gesteld door de eigenaren. Hiermee zijn metingen uitgevoerd van het aantal deeltjes (*Particle Number* of PN) in het uitlaatgas bij stationair toerental met behulp van verschillende (prototype) deeltjestellers. De metingen zijn zowel voor als na het roetfilter uitgevoerd.

Conclusies
Deeltjesemissies van dieselvoertuigen zonder roetfilter:
De 19 geteste diesel personen- en bestelvoertuigen zonder roetfilter hebben met een bedrijfswarme motor en bij stationair toerental een PN-emissie die varieert tussen 1 en 10 miljoen #/cm^3. Tevens blijkt de PN-emissie bij een koude motor tot wel tien keer hoger te zijn dan bij een warme motor. Deze gemeten emissies verschillen van metingen die eerder zijn uitgevoerd [10] met zeer oude dieselvoertuigen met zeer hoge kilometerstanden.

Deeltjesemissies van dieselvoertuigen met roetfilter:
Van dieselpersonen- en bestelwagens en vrachtwagens die zijn uitgerust met een roetfilter, is de deeltjesemissie bij stationair toerental veelal minder dan 5,000 #/cm^3. Dit is lager dan de deeltjesconcentratie in de buitenlucht. Een defect roetfilter is zeer eenvoudig te detecteren omdat de deeltjesemissie dan (veel) hoger is dan de deeltjesconcentratie in buitenlucht.

Deeltjesemissies tijdens het opwarmen van de motor van een dieselvoertuig:
Een dieselvoertuig met een goed werkend roetfilter kan na de koude start bij stationair toerental een relatief hoge deeltjesemissie hebben van meer dan 250.000 #/cm^3. Met een warme motor is de deeltjesemissie veelal minder dan 5.000 #/cm^3. Derhalve is de referentieconditie van een APK deeltjestest gekozen bij een warme motor. Een test die met een koude motor wordt uitgevoerd is echter ook geldig in de toekomstige APK deeltjestest.

Deeltjesemissies en EGR strategieën van dieselmotoren:
Door toepassing van uitlaatgasrecirculatie (EGR) kan de deeltjesemissie van een dieselmotor bij stationair toerental meer dan een factor tien toenemen. Dit leidt ook tot een in verhouding hogere deeltjesemissie na het roetfilter. De referentieconditie van een APK deeltjestest is gekozen met gesloten EGR-klep (geen uitlaatgasrecirculatie). Hiermee wordt voorkomen dat dieselauto's waarvan de EGR-klep is gemanipuleerd geen oneigenlijk voordeel hebben in de APK deeltjestest. Bij de meeste voertuigen sluit de EGR-klep na verloop van tijd automatisch of kan deze met behulp van een diagnosetester worden gesloten. Een test die met een open EGR-klep wordt uitgevoerd is echter ook geldig in de toekomstige APK deeltjestest.

Kortstondige verhoging van het motortoerental is niet mogelijk in deeltjestest:
De herhaalbaarheid van een APK-deeltjestest is nader onderzocht. Kortstondige verhogingen van het motortoerental (snap acceleration) gevolgd door stationair motortoerental leidt tot niet herhaalbare emissies in de deeltjestest omdat de EGR-klep niet op vaste tijdstippen wordt gesloten. Dit zou in de praktijk leiden tot niet herhaalbaar emissiegedrag en daarom moet het toerental gedurende de deeltjestest constant worden gehouden.

EOBD systemen voor detectie defecte roetfilters niet geschikt:
Van de 26 geteste diesel bestelwagens met roetfilter hebben 21 bestelwagens een PN-emissie bij stationair toerental die minder is dan 250.000 #/cm^3. Van de overige vijf bestelwagens, met een PN-emissie die hoger is dan 250.000 #/cm^3, blijken drie voertuigen een zeer hoge PN-emissie te hebben die ligt tussen 3.2 en 4.3 miljoen #/cm^3 . Slechts één van deze drie voertuigen geeft een actieve emissie gerelateerde melding op het EOBD systeem. Hieruit kan worden geconcludeerd dat huidige EOBD systemen niet altijd een melding geven in geval van een defect roetfilter en dus geen mogelijkheid bieden voor detectie van defecte roetfilters.

Deeltjesemissies van Euro VI vrachtwagens:
Euro VI vrachtwagens hebben soortgelijke deeltjesconcentraties bij stationair toerental als Euro 5 en 6 personen- en bestelwagens met roetfilter. Dit betekent dat de deeltjestest ook geschikt is voor vrachtwagens die zijn uitgerust met een roetfilter.

Welke PN limietwaarden kunnen in een APK-emissietest voor dieselvoertuigen met DPF worden gehanteerd?
Gezien de verschillende PM en PN limietwaarden in de typegoedkeuringstest voor Euro 5a (zonder PN-eis) en Euro 5b/6 dieselvoertuigen (met PN-eis) zijn verschillende PN limietwaarden in de APK-test mogelijk. In alle gevallen zal de limietwaarde voor een APK test minder streng moeten zijn dan 'In Service Conformity' eisen die in de typegoedkeuring worden toegepast. Een passende limietwaarde voor Euro 5b/6/VI dieselvoertuigen in een APK-test bij stationair toerentallen is 250,000 #/cm^3 en voor Euro 3, 4 en 5a voertuigen is deze 1,000,000 #/cm^3.

Hoe presteren de verschillende (prototype) deeltjestellers:
In dit project zijn ook metingen uitgevoerd met verschillende prototype deeltjestellers. Deze prototype deeltjestellers blijken onder bepaalde condities meetwaarden af te geven die substantieel afwijken van die van de voor dit onderzoek gebruikte referentiedeeltjesteller (TSI NPET) die voldoet aan

Zwitserse typegoedkeuringseisen. Verbeteringen lijken vooral mogelijk door verbeteringen van het monsternamesysteem en toepassing van een ‘volatile particle remover’ (VPR) die vluchtige deeltjes uit het monster verwijderd.

PN emissies van direct ingespoten benzinemotoren zonder GPF:
De deeltjesemissies van direct ingespoten benzinevoertuigen zonder roetfilter hebben duidelijke kenmerken, dit zijn:

- drie GDI motoren hebben bij laag stationair toerental in koude toestand een deeltjesemissie die ongeveer tien keer hoger is dan in warme toestand.
- bij verhoogd stationair toerental is de deeltjesemissie van GDI motoren 15 tot 130 keer hoger dan bij laag stationair toerental.

PN emissies van direct ingespoten benzinemotoren met GPF:
De deeltjesemissies bij stationair toerental van drie bedrijfswarme benzinevoertuigen met roetfilter zijn vergelijkbaar en dit zijn 1.000 tot 12.000 #/cm^3, direct na de koude start zijn deze echter 5 tot 1.000 keer hoger.
De deeltjesemissies voor twee geteste benzinevoertuigen met roetfilters blijken sterk te verschillen, dit zijn 100.000 en 5.800.000 #/cm^3.

Is deze nieuwe APK-PN-emissietest ook geschikt voor benzinemotoren?
De drie geteste roetfilters van benzinemotoren vertonen een soortgelijk filtratiegedrag als die van dieselmotoren. De geteste benzinemotoren blijken echter een verschillend PN emissiegedrag te vertonen en de PN-emissies kunnen bij laag stationair toerental wel een factor 50 verschillen. Aanvullend onderzoek met meer typen benzinevoertuigen met roetfilter is nodig voor de ontwikkeling van een universele APK deeltjestest voor benzinemotoren met roetfilter. Hierbij is ook aandacht nodig voor Euro 6d-temp voertuigen die niet zijn uitgerust met roetfilter.

Hoe is de toekomstige APK-deeltjestest voor dieselvoertuigen opgebouwd:
De in de laatste jaren uitgevoerde onderzoeken hebben geresulteerd in een voorstel voor een APK emissietestprocedure waarin bij stationair toerental de deeltjesemissie na het roetfilter in bijna alle gevallen in 10-30 seconden wordt gemeten.

Aanbeveling
De eerste verkennende emissiemetingen van benzinevoertuigen met roetfilter gemeten bij stationair toerental, vertonen ten opzichte van metingen bij dieselvoertuigen met roetfilter een afwijkend en niet eenduidig gedrag van de deeltjesemissies. Ook zijn er aanwijzingen van hoge deeltjesemissies bij een klein gedeelte van benzinemotoren met indirecte brandstofinspuiting. Voor ontwikkeling van een APK-deeltjestest voor benzinevoertuigen is daarom meer onderzoek nodig waarin de PN-emissies van diverse automerken/typen worden onderzocht.

Summary

Background
Wall flow particulate filters (DPFs and GPFs) are a very effective means to reduce emissions of soot particles in the exhaust gases of diesel and gasoline cars.
In 2002, diesel particulate filters made their appearance on the Dutch market for passenger cars and diesel particulate filters are used on a large scale since 2007, due to a fiscal stimulus. European Euro 5, 6 and Euro VI standards have meant that DPFs are now being applied to all new diesel vehicles. In particular, the particle number (PN) standard ensured robust filter technology. Since 2019 particulate filters have been applied on gasoline passenger vehicles with direct fuel injection.

Diesel particulate filters can be plugged or cracked. In these cases the DPF must be cleaned or replaced which can be very expensive. Therefore sometimes vehicle owners may decide to remove the DPF. Former executed studies of the share of vehicles with a defective or removed DPF indicate that this group of vehicles substantially contribute to the total PM10 emission of diesel vehicles with DPF.

The current emission tests in periodic technical inspections (PTI) are not capable to determine a good functioning DPF. Electronic On Board Diagnostic (EOBD) systems of the vehicle are not able to detect DPF failures. In case of a DPF removal the engine management is manipulated and the removal of the DPF won't be detected by the EOBD system.

Detection of DPF failures in the PTI is only possible when the requirements become more severe and a more sophisticated emission test is implemented. If the implementation of a new PTI emission test will not take place, a substantial amount of vehicle owners may decide to remove the DPF, saving operational costs.

In 2017 TNO proposed a new PTI test method for diesel vehicles with a particulate filter [1]. This test is executed at low idle speed and PN emission is measured. A possible PN limit value for Euro 5b/6 vehicles, which have to satisfy the type approval PN standard, is 250,000 #/cm^3 and Euro 3, 4 and 5a vehicles, with only a particle mass standard based on a filter test, may have a PN limit value of 1,000,000 #/cm^3

In this research study the PTI PN emission test procedure and the PTI PN limit values of diesel vehicles are further investigated and assessed. Furthermore first tests with gasoline vehicles with GPF are executed and potential PTI PN limit values investigated.

Aim and approach
In order to be able to assess the condition of particulate filters in the PTI the Dutch Ministry of Infrastructure and Water Management asked TNO to investigate PTI PN limit values and to obtain more reliable emission data as a basis for determination of emission limit values for periodic technical inspections (PTI). In this report the results of this project are described.

Within this project 51 diesel vehicles and 6 gasoline vehicles were tested by TNO using different test procedures. The vehicles were Euro 3,4, 5 and 6 class vehicles which were rented or borrowed from private owners. PN emission tests were performed with different (prototype) particle counters and samples were taken pre and post DPF. Furthermore detailed tests with EGR systems were executed. The test results were used to design and propose new PTI PN limit values to identify vehicles with a malfunctioning or removed DPF.

Conclusions

PTI PN emissions of diesel vehicles without DPF:
The PN emission of the tested vehicles at low idle speed of cold engines without DPF is higher than warm engines and at high idle speed the PN emission is higher than at low idle speed.
PN emissions at low idle speed of six warm Euro 3 diesel engines without DPF were 2 to 9.4 million #/cm3 and thirteen Euro 4 vehicles without DPF emitted 1.0 to 10 million #/cm3. These measured emission trends deviate from former tested very old diesel vehicles with very high mileages.

PTI PN emissions of diesel vehicles with DPF:
The PN emission at low idle speed of warm engines with DPF are often less than 5,000 #/cm^3 and lower than the PN concentration of ambient air. Defects of DPF's can easily be detected because than the PN emission is higher than the PN concentration in ambient air.

PN emissions of diesel vehicles during warming up of the engine:
After a cold start of a diesel vehicle with DPF in good condition the PN emission at low idle speed can be relatively high (>250,000 #/cm^3). However after warming up of the engine the PN emission can be less than 5,000 #/cm^3. As a result of the warming up behavior of a diesel vehicle with DPF the reference condition for a PTI test is a warm engine.

PN emissions and EGR strategies of diesel engines:
The application of EGR can increase the PN emission of an engine at low idle speed with a factor more than 10. This may increase the post DPF PN emission as well. In order to create stable and defined PTI test conditions the EGR actuator valve must be closed. Consequently manipulation of the PTI test is prevented.
For most vehicles at low idle speed the EGR valve actuator closes after a certain time. For other vehicles EGR valves can be closed with a diagnostic tester.

Snap accelerations cannot be part of the test procedure:
Snap accelerations followed with low idle speed operation seem to result in a non-defined engine behaviour because in consecutive tests the EGR valve will be activated/opened and after a certain non-repeatable time closed. Practically this results in varying stabilisation times of the PTI test and therefore the engine speed must be kept stable in the PTI-test.

OBD systems cannot detect DPF failures:
Three out of twenty six tested vehicles with DPF had very high PN emissions at low idle speed (3.9 - 5.3 * 10^6 #/cm^3) and only one of the three high emitters had an active emission related OBD fault code. This indicates that OBD systems are not well designed to detect DPF failures.

PN emissions of Euro VI trucks:
Euro VI trucks have similar PN emission behaviour as light duty diesel vehicles with DPF and consequently the PTI PN test can be applied for trucks and buses with DPF's.

What are feasible PN limit values in the PTI for diesel vehicle with a DPF?
Based on the different PM and PN type approval limit values of Euro 5a and Euro 5b/6 diesel vehicles different PTI-PN limit values can be chosen. In all cases the PTI-PN limit value must be less stringent than the limit values of In Service Conformity tests. The former proposed PTI PN limit value of 250,000 #/cm^3 at low idle speed seem to be a reasonable value for all tested Euro 5b, 6 and VI diesel vehicles. For Euro 3, 4 and 5a vehicles a PTI PN limit value of 1,000,000 #/cm^3 is proposed.

Performance of prototype PTI PN testers:
Prototype PTI PN testers sometimes are in line with a certified PN tester (TSI 3795) but can also deviate up to more than 300%. A lack of sample conditioning and the absence of a volatile particle remover (VPR) in the prototypes seem to be the major reasons for the measured PN deviations.

PN emissions of direct injected gasoline vehicles without GPF:
The PN emissions of the tested GDI vehicles without GPF show clear trends, these are:

- Three cold GDI engines at low idle speed have approximately 10 times higher PN emissions (1.7 to 5.0 * 10^5 #/cm^3) than warm engines which emit 1 to 6 * 10^4 #/cm^3.
- At high idle speed the PN emission of the GDI engines is 1.5 * 10^5 to 8 * 10^6 #/cm^3 and this is 15 – 130 times higher than the PN emission at low idle speed.

PN emissions of direct injected gasoline vehicles with GPF :
Tail pipe PN emissions at low idle speed of the three warm tested GDI vehicles with GPF are comparable and in the range of 1,0 * 10^3 to 1,2 * 10^4 #/cm^3 but just after a cold start they can be 5 - 1000 times higher. However, the engine out PN emission (pre GPF) of two tested vehicles at low idle speed are not comparable and are 1.0 * 10^5 and 5.8 * 10^6 #/cm^3.

Can the new PTI-PN test procedure be applied in gasoline vehicles?
The three tested gasoline particulate filters have a similar filtration behaviour as diesel particulate filters. However the PN emissions of gasoline engines can be up to 50 times lower than diesel engines. For the development of a PTI-PN test procedure for gasoline vehicles with GPF additional research is needed.

PTI-PN test procedure for diesel vehicles:
The research activities of last years resulted in a proposal for a PTI test procedure for diesel vehicles with DPF with a particle counter. It contains three elements which are: an emission test at low idle speed, a specification of a particle counter and a PTI-PN limit value which is described in Appendix G.
For most vehicles this test procedure can be executed in 10 - 30 seconds.

Recommendation
First investigations of PN emissions of gasoline vehicles and GPF's show PN emission trends which are not in line with the PN emission behaviour of diesel vehicles with DPF. It is recommended to measure and study the PN emissions of different gasoline vehicles with GPF and the specific emission behaviours. These results can be the basis for simple PTI tests. Moreover, there are indications that gasoline vehicles without direct injection, which do not have to satisfy a PM or PN standard may have high particulate matter emissions.

Contents

1 Introduction

1.1 Introduction

In 2012 the Dutch Ministry of Infrastructure and Water Management requested TNO to start research activities for the development of a test procedure of diesel particulate filters in periodic technical inspections (PTI).

In a first study the possibilities for application of opacimeters or smoke meters in the PTI was investigated [5]. The second study combined EOBD and smoke tests and visual inspections [6]. In 2016 an investigation of 220 light duty diesel vehicles with smoke meters and a particulate number counter was performed [7] and the application of a PN counter was promising. Additionally in 2017 more prototype PN counters were tested because in the future PTI stations need test equipment at a lower price level. Furthermore PTI test results were validated against PM and PN emissions on the chassis dynamometer [1].

In 2018 a further investigation of potential PTI-PN limit values has started.
This report presents detailed results of particulate number (PN) emission tests carried out by TNO in the period autumn 2018- summer 2019. The tests focussed on emissions of in-use, older, diesel vehicles with and without a diesel particulate filter (DPF) and high mileages.

On the basis of the executed research activities from 2012 to 2019 the Dutch Ministry of Infrastructure and Water Management requested TNO to set up a proposal of a PTI test procedure for checking the condition of a diesel particulate filter (DPF) by means of a particle counter.

This research activity is part of the Dutch in use compliance (IUC) test program for light duty vehicles which is executed on behalf of the Dutch Ministry of Infrastructure and Water Management by TNO.

1.2 Context

Periodic Technical Inspection:
In the European Union the roadworthiness testing of vehicles is described in Directive 2014/45/EU. One of the primary articles is:

> *Roadworthiness testing is a sovereign activity and should therefore be carried out by the Member States or by public or private bodies entrusted to carry out such testing under their supervision. Member States should invariably remain responsible for roadworthiness testing, even where the national system allows for private bodies, including those which also perform vehicle repairs, to carry out roadworthiness testing.*

In order to comply with this directive member states have to develop and define roadworthiness tests and periodic technical inspections. As part of this obligation the described PTI PN test procedure has been developed in The Netherlands.

The development of a test procedure for the periodic technical inspection of vehicles with a particulate filter contains a few elements which were studied in detail in the past years.

These elements are:

- Specifications of a PTI PN tester.
- PTI PN test procedure.
- PTI PN emission limit values.

Gasoline vehicles with GPF:
Since 2018 direct-injection gasoline vehicles with GPF enter the European market. Their specific PN emission behaviour is unknown. In order to investigate the possibilities for a PN emission test in the periodic technical inspection a first set of emission tests was performed.

1.3 Aim and approach

The aim of the project was to assess the PN emission performance of diesel and gasoline vehicles of different Euro classes without DPF/GPF under PTI test conditions, to determine the behaviour of exhaust gas recirculation (EGR) systems and to make a more advanced argumentation for PTI PN limit values.

In order to check the validity of the developed test procedure and to set a robust PTI-PN limit value detailed PN tests were carried out with LD & HD vehicles with different technologies and the performances of prototypes of PTI-PN instruments were assessed.

Finally the collected knowledge should allow to define a proposal for a PTI-PN test procedure.

1.4 Structure of the report

Information regarding the selection and the basic specifications of the selected vehicles can be found in Chapter 3. This chapter also provides detailed information about the emission tests and the applied test equipment.
Chapter 4 presents overviews of the test results for the tested vehicles,
In Chapter 5 a proposal for a PTI particulate filter test with a particle counter is described, followed by conclusions in Chapter 6. Chapter 7 gives recommendations for further research.

All test results of the individual vehicles as well as a full proposal for a PTI particulate filter test with a particle counter are part of the Appendices.

2 Considerations with regard to a PTI PN test procedure

2.1 Overview of in-use vehicles investigations

Although it is known that DPF's may fail and are removed, the size of the scale is unknown. In time several fleet investigations were published and they give indications of the condition of these fleets. Below a summary is given.

2014: Dutch national PTI investigations (RDW) of 355 LD-vehicles [6]: 21 vehicles have increased smoke emissions ($k > 0.50\ m^{-1}$). It is estimated that 5-7% has a defective or removed DPF.

2016: Field investigations (TNO) of 215 ex-lease LD-vehicles [7], 19 vehicles have a PN emission at low idle speed higher than 250,000 $\#/cm^3$ (8.8% fail).

2018: Dealer and workshop interview study (TNO) of removal of DPF's in Dutch service shops [9] : It is estimated that at least 1,2% of the Dutch diesel vehicles have a removed DPF.

2019: Field investigations (GOCA Belgium) of 349 LD vehicles [8] 45 vehicles have a PN emission at low idle speed higher than 250,000 $\#/cm^3$ (15% fail).

2019: Field investigations (Kanton Zurich) of >700 LD vehicles [4] 70 vehicles have a PN emission at low idle speed higher than 250,000 $\#/cm^3$ (10% fail).

2019: Field investigations (TNO) of 26 older LCV's, published in this report in section 4.2, Five vehicles have a PN emission at low idle speed higher than 250,000 $\#/cm^3$ (19% fail).

2019: Field investigations (RDW) of 126 passenger cars, 83 LCV's and 27 HD vehicles (mainly Euro VI trucks). Based on proposed limit values the PTI failures rates are: passenger cars 14%, LCV's 11% and trucks 4%. A more detailed overview is given in Appendix H.

These studies of the share of vehicles with a defective or removed DPF don't cover the total fleets of diesel vehicles of the different countries. However they indicate that vehicles with a defective or removed DPF substantially contribute to the total PM10 emission of diesel vehicles with DPF.

2.2 Fleet considerations

Diesel vehicles without DPF are already less than 10% of all Dutch diesel vehicles on the road and this fraction reduces rapidly, with more than 5% per year reduction. Consequently, this major source of small particles and elemental carbon emissions is disappearing rapidly. The eventual emission level of the road vehicle emissions of exhaust gas particles, towards 2025, depends currently three unknown factors.

- First, the effectiveness of the new PTI procedure to detect and correct faulty and removed DPFs. Important steps are made to ensure this effectiveness, as shown in this study.

- Second, the particle emissions of port-injection gasoline vehicles for which there is not emission legislation.
- Third, the durability and retention of GPF for direct-injection gasoline vehicles [13]. Older gasoline cars have shown no durability problems of particle emissions of any consequence [14], [15].

2.3 Air quality and health considerations

With increasingly lower particulate matter emissions on the type approval tests, the particle number test provided an accurate and robust alternative measurement to ensure low particulate matter emissions of diesel vehicles. This particle number test protocol, the PMP, was introduced for all combustion technologies with the risk of high particle emissions, with associated PN (solid particle number) limits. It effectively replaced the filter test, with the particulate mass (PM) limits, as the most stringent criterion for particle emissions of on-road vehicles and mobile machinery.

With the current understanding from the WHO that there is no safe concentration of fine particulate matter in the ambient air, combined with the significant reduction of diesel engines vehicles without particulate filters, the attention remains also on the low concentrations of particulate matter. Therefore, the smaller sources of particulate matter emissions need to be identified. The test results of PN emission tests are only indicative of the magnitude of these sources. The particle number emissions in idle tests and with measurement procedures to strip the volatile part, have limited relation with the average particulate matter, i.e., particulate mass, emissions and particle matter concentrations in the air.

In ambient air, three types of measurements are used in particle-related air-quality correlated with health issues: PM10 (all particulate mass below 10 micron), PM2.5 (all particulate mass below 2.5 micron), and EC (Elemental Carbon mass concentration) [11], [12]. Since PN emission testing is becoming the de-facto standard both in real driving emission (RDE) as in PTI tests, it is important to establish a link between these test results and air-quality concentrations, to establish the true impact on air-quality of reducing particulate number (PN) emissions. Such a link may depend on the combustion technology. For example, particulate matter emissions of spark ignition engine technology have higher volatile fraction of solid particles and volatile particles than diesel engine technology, which are not fully accounted for in the particle number (PN) tests.

2.4 Technical considerations

Conditions of vehicles:
For the development of a PTI PN test procedure one should give attention to all possible conditions of vehicles.

For diesel vehicles these are:
1. No DPF.
2. DPF in good condition.
3. DPF with restricted filtration efficiency.
4. DPF canning present, removed filtration element.
5. DPF completely removed and replaced by a straight pipe.
6. Half open particulate filter with a filtration efficiency of 20-50%.

PN emission pre and post DPF are mostly very different.
Diesel engines run with a wide range of air-fuel ratios and Exhaust Gas Recirculation (EGR) rates and this results in a very dynamic PN emission behaviour of engines. This should be taken into account when setting up a robust PTI test procedure that can be applied on all vehicles with a particulate filter.
In former research projects [1] the pre and post DPF PN emissions of diesel vehicles under PTI conditions were investigated. In Figure 2-1 measured ,up front the DPF, the PN emission of a Ford Fiesta at low idle speed was 2 to 17 million #/cm^3. Vehicles with a DPF in good condition often emit less than 5,000 #/cm^3. This huge difference of the PN emissions pre and post DPF is a good basis for a PTI PN test procedure.

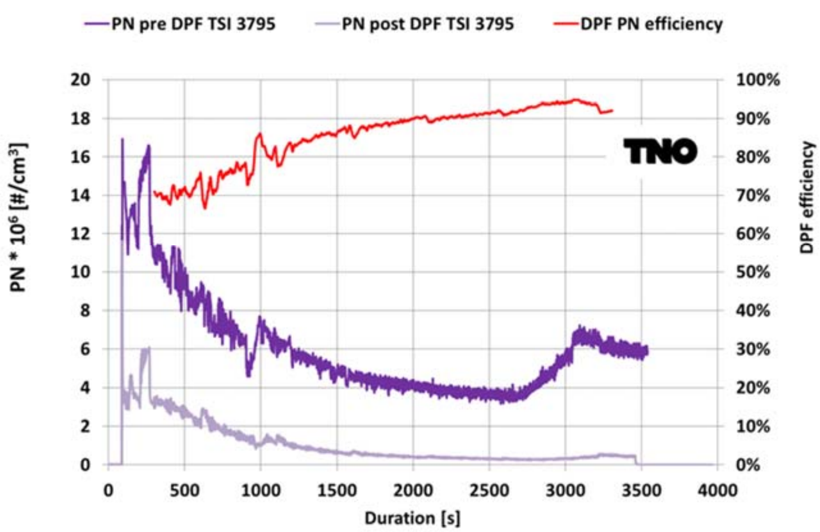

Figure 2-1: PN emission pre and post DPF during warming up at low idle speed of a Ford Fiesta Euro 6b diesel engine with small DPF leakage.

Future PTI PN test procedure:
In future periodic technical inspections a DPF is checked by measuring the PN emission in the tail pipe of the vehicle when the engine is running at low idle speed. After installation of the PN sample line in the tail pipe of the vehicle the PN volumetric concentration of exhaust gas is measured. This PTI test takes less than 1 minute (preparation, stabilisation of the PN-tester and emission measurement).

PTI PN limit values:
First technological investigations [1] of the PTI PN limit value of Euro 5b and Euro 6 diesel vehicles with a DPF indicated a PTI PN limit value of 250,000 #/cm^3. Another Belgian PTI study [8] in which 263 Euro 5 and 41 Euro 6 diesel passenger cars were tested, gained a PTI failure rate of 15.2 % applying a PTI PN limit value of 250,000 #/cm^3. Because Euro 3, 4 and 5a vehicles with a diesel particulate filter have only a PM limit value of 5 mg/km in their type approval test and no PN limit value, it is proposed to define the Dutch PTI PN limit value of vehicles which were registered before 1-1-2015 on 1,000,000 #/cm^3. Vehicles which were registered after 1-1-2015 will have a PTI-PN limit value of 250,000 #/cm^3.

PTI versus In Service Conformity

In a former TNO research program [1] it was investigated that the PTI PN limit value of 250,000 #/cm³ at low idle speed is less stringent than the Euro 5a and 6 type approval PN limit value of 6.0 * 10^{11} #/km, see Figure 2-2. The (meanwhile updated) figure also shows a very good correlation between a PTI-PN emission in #/cm³ at low idle speed and the PN emission of an NEDC test in #/km.

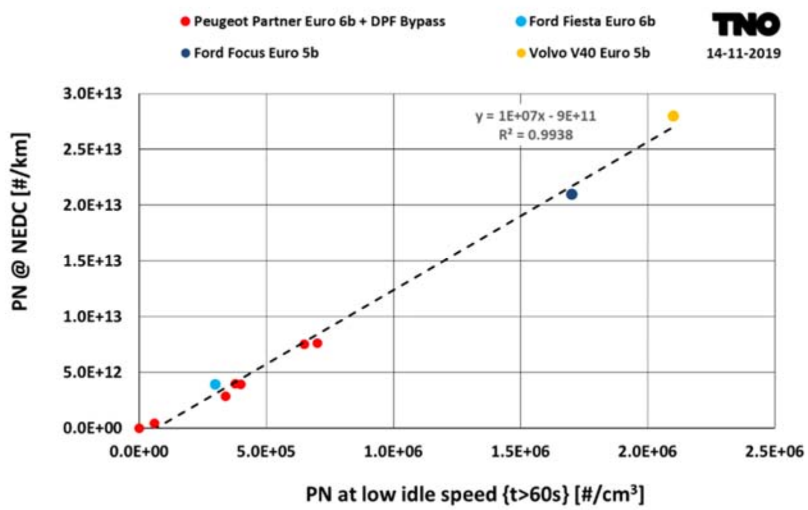

Figure 2-2: PN emissions at low idle speed measured with TSI NPET and NEDC tests of 4 different diesel vehicles with (cracked) DPF or variable bypass. The PN emission at low idle speed was measured with a closed EGR valve.

The PTI-ISC relationship of PN emissions was also investigated and confirmed by EC-JRC [2]. These data of Figure 2-3 also show that vehicles with a PTI-PN emission of 250,000 #/cm³ at low idle speed have a PN emission in the NEDC test which is substantial higher than the PN type approval limit value of 6.0 * 10^{11} #/km. From these results it can be concluded that a PTI-PN limit value of 250,000 #/cm³ is less stringent than a NEDC limit value of 6.0 * 10^{11} #/km.

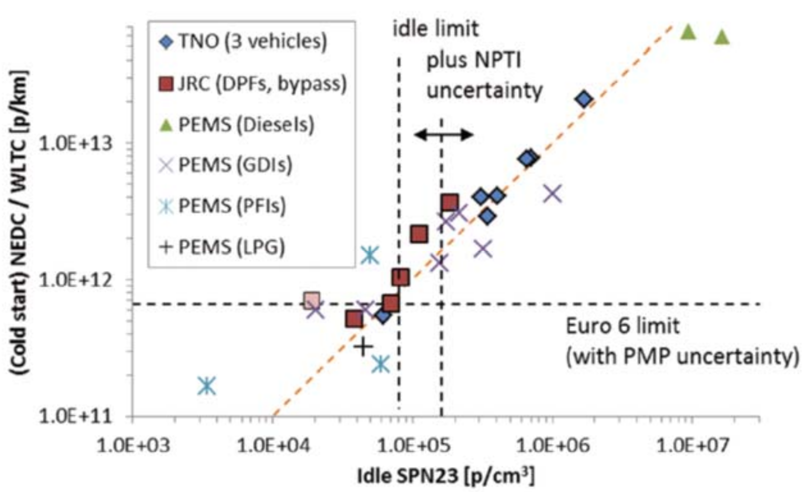

Figure 2-3: PN emissions at low idle speed and NEDC/WLTC tests of different vehicles (with DPF or variable bypass), source JRC [2].

The need for new low cost PTI PN test equipment
In Europe the number of PTI stations is quite high because a few member states (i.e. United Kingdom, Germany, The Netherlands) have (partly) a decentralised PTI system. Every commercial workshop can be certified for PTI's. This requires a need for low cost emission testers.
In 2018 in The Netherlands the Ministry of Infrastructure and Water management requested the national metrological institute (NMi) to set up a national standard for a PTI PN tester including (in field) calibration procedures. This initiative was embedded in the informal international working group of VERT (Verification of Emission Reduction Technologies) and developed with several stakeholders (equipment manufacturers, PTI organisations and scientific organisations). As member of this VERT-NPTI group Burtscher published a broad overview of existing measuring technologies [4]. In 2019 the Dutch national specification of the PTI PN tester[1] was published in the Dutch Journal of State (Staatscourant) and NMi published the specifications on their website, part 1 describes the specifications of the instrument and part 2 defines calibration procedures.
Article: https://www.nmi.nl/markets/mobility/
Proposals: https://www.nmi.nl/special-particle-number-counters/

International developments PTI PN test equipment
In 2018 a new project at the Mondial OIML (International Organisation of Legal Metrology in Paris) has been started. The minutes of the 53rd CIML Meeting (OIML workgroup), Hamburg, Germany 9–12 October 2018 report:
Resolution no. 2018/27 (agenda item 12.1.2.5) The Committee, Noting the comments made by its members on the details of the terms of reference included in Addendum 12.1.2.5, Approves as a new project, under the responsibility of TC 16/SC 1, the development of a new Recommendation on Instruments for measuring the vehicle exhaust soot particle number (PN), to be conducted as specified in the project proposal provided in the addendum 12.1.2.5 to the working document of this meeting.

[1] https://zoek.officielebekendmakingen.nl/resultaten?q=(available%253e=2019-11-22)and((publicationName==%22Staatscourant%22and(jaargang==2019)and(publicationissue==%2263953%22)))&zv=&col=Staatscourant

3 Test Program

3.1 Tested vehicles

In this test program different in use diesel and gasoline vehicles of different emission classes were tested.

In Table 3-1 an overview of the tested LD and HD diesel vehicles is given.
In Table 3-2 an overview of the tested LD gasoline or GDI vehicles is given.

Table 3-1: Overview of tested LD and HD diesel vehicles with/without DPF

Euro class	Number	No DPF	With DPF
3	7	6	1
4	22	13	9
5a	6	0	6
5b	3	0	3
EEV	5	0	5
6b	2	0	2
6d-temp	1	0	1
VI	5	0	5
Total	**51**	**19**	**32**

Table 3-2: Overview of tested LD GDI vehicles with/without GPF

Euro class	Number	No GPF	With GPF
5	2	2	0
6b	1	1	0
6d-temp	3	0	3
Total	**6**	**3**	**3**

3.2 Emission tests

In this test program all emission tests were performed at idle speeds with cold and warm engine starts. In some experimental tests certain increased PN emission levels in the tail pipe were needed. Therefore an artificial bypass was created, the pressure sensor of the DPF was disconnected and the two sample lines (pre and post DPF) connected, creating a higher PN emission post DPF.

3.3 Test equipment

In Table 3-3 some characteristics of the applied PN counters of this project are specified. Only one device (TSI 3795 or NPET) is type approved, the other PN-counters are prototypes. Some devices were equipped with a volatile particle remover (VPR). In general the PN counters are built with a condensation particle counter (CPC) or a diffusion charger with sensitive electrometer (DC).

Table 3-3: Details of applied PN counters

Trade mark	TSI	TSI	TSI	Sensors	Naneos
Type	NPET	PTI	APET	APA	Partector
Status device	Approved	Proto	Proto	Proto	Proto
VPR	Yes	No	Yes	No	No
Sample dilution	Yes	Yes	Yes	Yes	No
Measuring principle	CPC	CPC	CPC	CPC	DC
Meas. range [#/cm³]	$50 * 10^6$	$5 * 10^6$	$5 * 10^6$	$5 * 10^6$	$5 * 10^6$
Particle size range [nm]	23 - 1000				10 - 10,000
Power source	230V	Battery	Battery	Battery	Battery

Figure 3-1: Different (prototype) PTI PN testers.

Specification of the PN counter:
Currently most PN-counters are not yet certified. In this project the PN tests are mainly carried out with two handheld prototype PN counters (TSI-PTI and TSI-APET, status June 2018 and June 2019) which were validated against a TSI 3795 PN counter (NPET). This TSI NPET device complies nearly with the specifications of the PN counter that has been applied in a type approval emission test on the chassis dynamometer (PMP-protocol). Some tests were also performed with the PN-counters of Sensors and Naneos.

4 Results

4.1 PN emissions of light duty diesel vehicles without DPF

In order to get a clear view on PN emission behaviour of engines without DPF some vehicles were tested. Figure 4-1 shows PN emissions at low idle speed of five Euro 3 and eight Euro 4 light commercial vehicles without DPF.
The PN emission at low idle speed with a warm engine is in the range of 1 to 9.4 million #/cm³. The status of the EGR-systems of these vehicles is unknown.

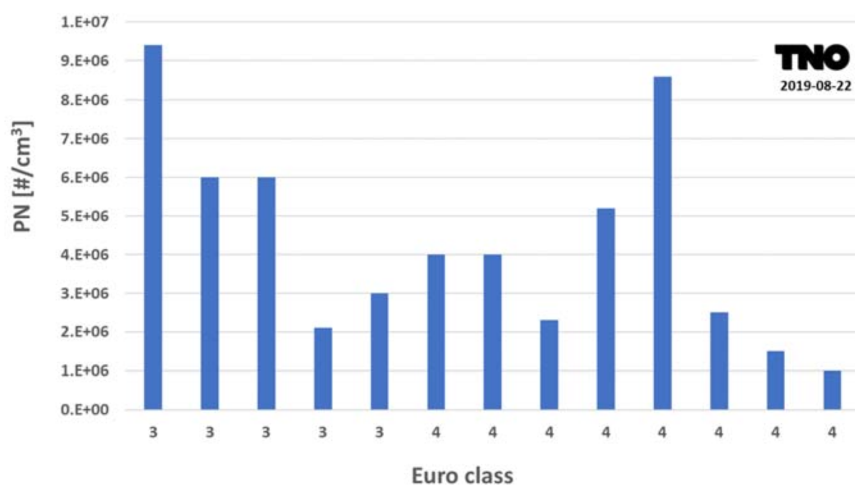

Figure 4-1: PN emissions at low idle speed of five Euro 3 and eight Euro 4 light commercial vehicles with warm diesel engines and without DPF, measured with a prototype TSI PTI PN counter without VPR.

In a second test session diesel vehicles were tested at different temperatures.
In Figure 4-2 the PN emission at low idle speed at different engine temperatures of Euro 3, 4 and 6 N1 Class 3 light commercial vehicles is shown. The PN emission of these tested Euro 3 and 4 vehicles with a cold engine at low idle speed is higher than the PN emission of a vehicle with a warm engine. Furthermore the PN emission of vehicles with warm engines at high idle speed is higher than at low idle speed. This is not in line with the PN emissions at low and high idle speed of very old vehicles with very high mileages [10] The three vehicles with DPF have substantial lower PN emission at low idle speed than vehicles without DPF.

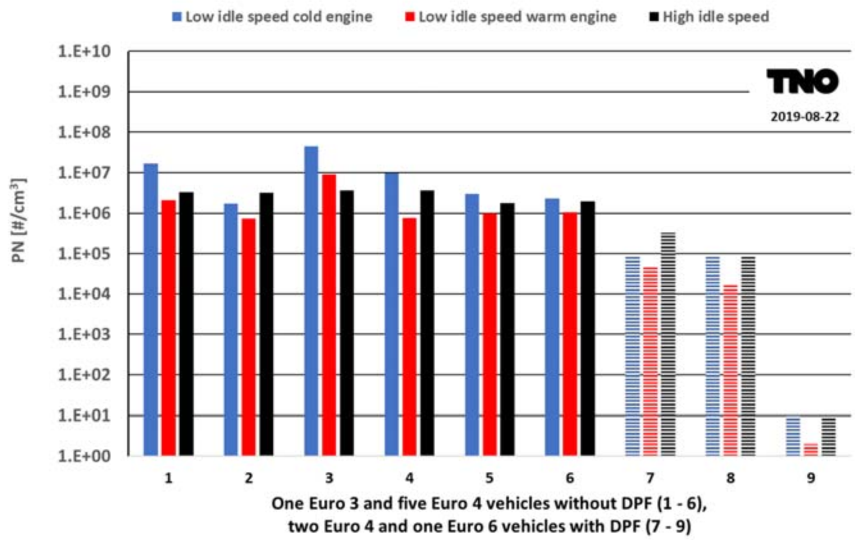

Figure 4-2: PN emissions at idle speeds of 9 N1 Class 3 light commercial vehicles with and without DPF with cold and warm engines measured with a prototype TSI PTI PN counter without VPR.

PN emissions are dependent on the operating conditions of the engine.
In Figure 4-3 the PN emissions of an Euro 6b engine with different EGR rates are plotted. The PN emission at low idle speed with EGR is in the range of 7 to 12 * 10^6 #/cm^3. With less EGR the PN emission is 3.5 to 6.5 * 10^6 #/cm^3.
It can be concluded that the conditions of the combustion of an engine determine the PN emission. One of the primary parameters is the air-fuel ratio. In general high air fuel ratios result in low PN emissions because relatively high amounts of air are available for combustion.
In order to reduce NO_x emissions Exhaust Gas Recirculation (EGR) is applied. With applied EGR exhaust gas replaces air and the air-fuel ratio will reduce. Consequently the NO_x emission decreases but the PN emission increases.

The application of EGR has substantial effect on the PN emission of an engine at low idle speed. With the application of EGR the oxygen content in the air-fuel mix is lower, leading to a poorer combustion, with the risk of high particle numbers. EGR application also reduces the exhaust gas flow, increasing the PN-concentrations. Low EGR rates generate a low PN emission.
With respect to a new PTI-PN test at low idle speed the condition of the engine operation must be defined (i.e., position EGR-valve).

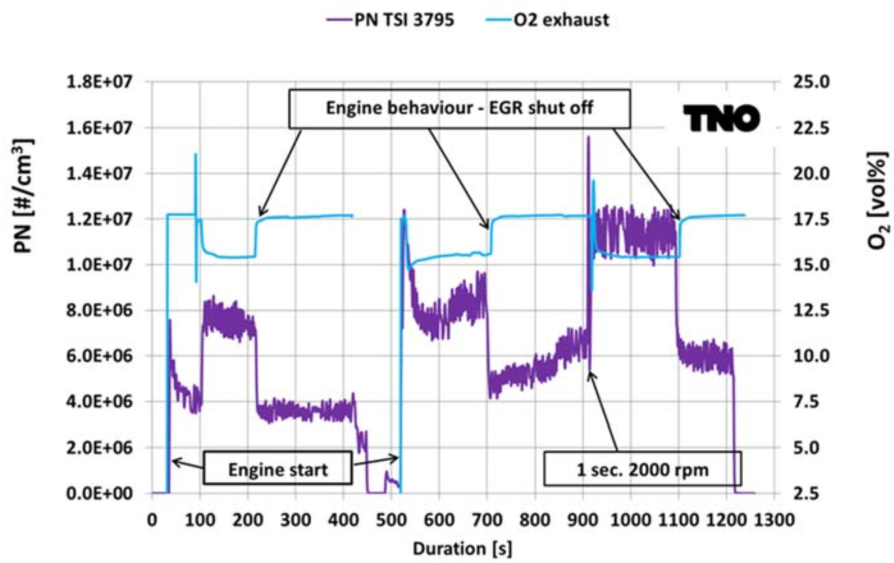

Figure 4-3: PN and O_2 emissions pre-DPF after two engine starts of a Ford Fiesta Euro 6 diesel engine with small DPF leakage at low idle speed.

4.2 PN emissions of light duty diesel vehicles with DPF

Light duty vehicles

Figure 4-4 shows PN emissions at low idle speed of 23 in use Euro 3, 4, 5a, 5b, 6 and EEV light commercial vehicles with DPF. The PN emissions at low idle speed with a warm engine are in the range of 100 to 4,300,000 #/cm^3. Sixteen vehicles have a PN emission of 100 to 50,000 #/cm^3, these DPF's are in good condition. However seven vehicles have elevated PN emissions, four vehicles at a level of 170,000 to 520,000 #/cm^3 and three vehicles are high emitters with a PN emission of 3,2 to 4,3 million #/cm^3. These seven vehicles with elevated PN emissions have probably a (substantial) DPF failure, compared to a functioning DPF.

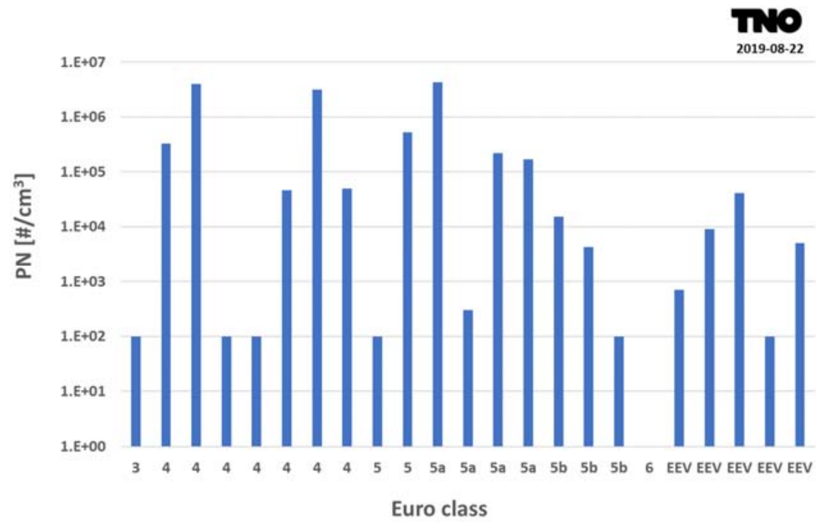

Figure 4-4: PN emissions of warm diesel engines of 23 N1 Class 3 light commercial vehicles with DPF at low idle speed; 18 vehicles have a PN emission below 250,000 #/cm^3 and 5 vehicles have a PN emission above 250,000 #/cm^3.

From all vehicles the EOBD system was checked and pending and stored fault codes registered (see Appendix C). Three vehicles with DPF had pending EOBD codes.

1. Mercedes Viano with 369,040 km with EOBD code P0473 (exhaust pressure sensor high input) and a PN emission at low idle speed of 4.9 * 10^6 #/cm^3.
2. Mercedes Vito with 284,834 km with EOBD code P0103 (mass air flow circuit high) and a PN emission at low idle speed of 120 #/cm^3.
3. VW Crafter with 183,004 km with EOBD codes P229F (NOx sensor circuit) & P068A (ECM?PCM power relay) and a PN emission at low idle speed of 11.000 #/cm^3.

Only the Mercedes Viano has an extremely high PN emission and an EOBD fault code but the two other vehicles had EOBD fault codes with very low PN emissions at low idle speed.
Two out of three vehicles with a DPF failure did not give an EOBD fault code. So these EOBD systems cannot detect DPF failures.

The former proposed PTI PN limit value of 250,000 #/cm^3 at low idle speed [1] seem to be a reasonable value for all tested diesel vehicles.

4.3 PN emissions during warming up

4.3.1 PN emissions during warming up of a Peugeot 308 diesel Euro 6d-temp

In Figure 4-5 the PN emission of a Euro 6d-temp Peugeot 308 with diesel engine with DPF is shown. The test was started at t = 350 s with a cold engine.
The total duration of this test is 28 minutes. At low idle speed the PN emissions were constantly measured. The PN emissions of the TSI-NPET and TSI-APET are very similar.

Just after the start of the engine the PN emission is 400,000 #/cm^3 and after a warming up of 20 minutes at low idle speed the PN emission was reduced to less than 1,000 #/cm^3 which is lower than the actual PN concentration of ambient air. In order to get an impression of the repeatability of the PN emission the vehicle was run from t = 1500 to 1750 s in a road trip and in addition the PN emission at low idle speed was measured which again came to a level of less than 1,000 #/cm^3. From this experiment it is very clear that the PN emission of a diesel vehicle with DPF depends on the actual operating temperature of the engine and DPF.

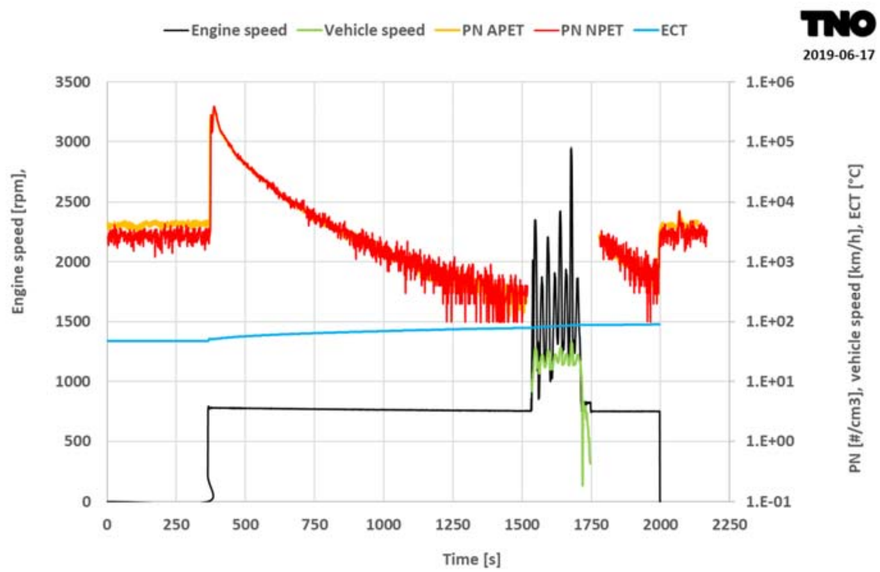

Figure 4-5: PN emissions post DPF at low idle speed during warming up of the engine of a Peugeot 308 Euro 6D-Temp diesel. From 1550 to 1750 s a warming up trip on a parking lot was performed.

4.3.2 *PN emissions during warming up of a VW Caddy diesel Euro 6b*

In Figure 4-6 the PN emission of 26 consecutive PTI tests at low idle speed of a Euro 6b VW Caddy with diesel engine and a DPF bypass is shown. The bypass was created to simulate a DPF leakage. The test was executed with an open DPF bypass and started with a cold engine and PN emissions were measured post DPF at low idle speed with five different PN testers. After each idle test the vehicle was run and further warmed up on a parking lot for a few minutes and at that time the PN testers sampled ambient air. The total duration of this test is 123 minutes. After the tenth idle test (t=2250 s) the PN emission drops abruptly from approximately 1,500,000 to 100,000 #/cm^3. In Figure 4-7 around t=2250s the PN emission and actual oxygen concentration of exhaust gas is plotted. With an oxygen concentration of 13.5 vol% (EGR activated) the PN emission at low idle speed is 1,400,000 #/cm^3 and in case of an oxygen concentration of 17.7 vol% (EGR deactivated) the PN emission is 90,000 #/cm^3. From these numbers it is clear that EGR may affect the PN emission of an engine up to a factor of 15. This specific EGR control strategy is meant for control of the NOx emission in the warming up phase. As soon as the SCR catalyst is warmed up and active, the EGR-system is less active or shut off. After the 20st PTI test the vehicle was warmed up in a longer trip so the exhaust gas temperature increased.

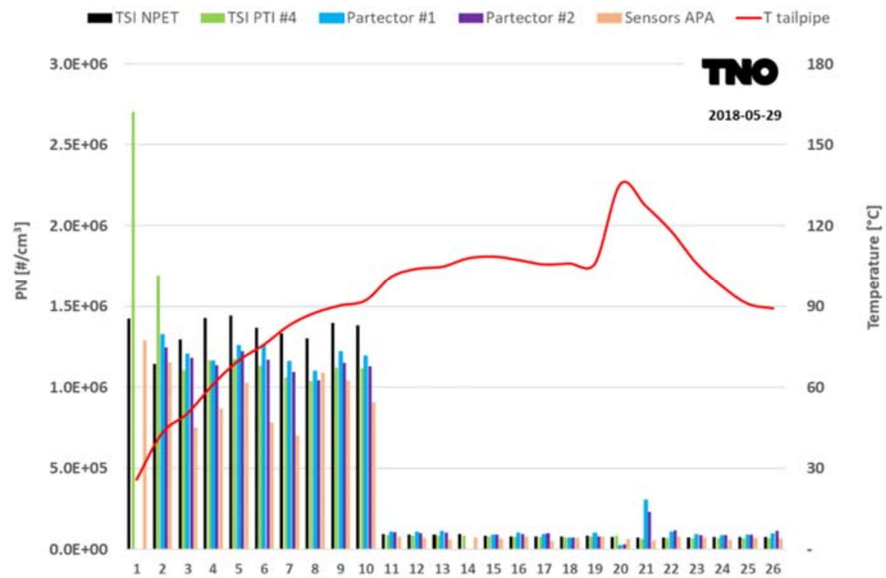

Figure 4-6: PN emissions of 26 consecutive low idle speed tests with 5 PN-counters at low idle speed of VW Caddy Euro 6b diesel vehicle with DPF bypass and measured post DPF. The test was executed with an open DPF bypass and started with a cold engine.

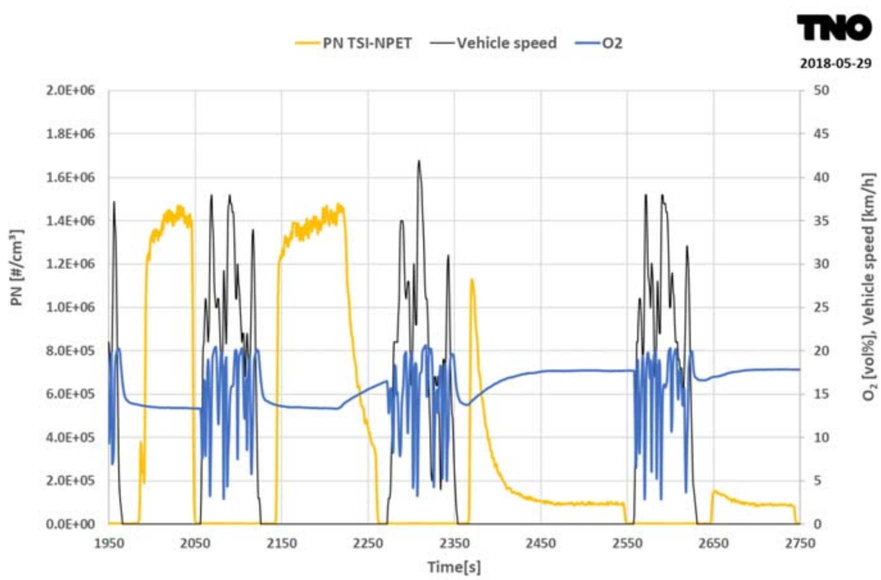

Figure 4-7: PN emissions of consecutive low idle speed tests with 1 PN-counter at low idle speed around a switch point of the EGR control of a VW Caddy Euro 6b diesel vehicle with DPF bypass. With an oxygen concentration of 13.5 vol% (EGR activated) the PN emission at low idle speed is 1.4 E06 #/cm^3 and in case of an oxygen concentration of 17.7 vol% (EGR deactivated) the PN emission is 9.0 E04 #/cm^3.

In Figure 4-8 the average PTI PN test results of 16 of 26 PTI tests with five (prototype) PN testers are shown. In this test session the engine was started at cold conditions and warmed up.

During the first 10 PTI tests with a PN emission of more than 1 million #/cm^3 the certified TSI NPET with VPR and sample dilution at the tip of the sample line shows relatively stable PN emission but the TSI proto without VPR and the Sensors APA sample line have less stable PN test results in this warming up phase. The Partectors without VPR and without sample dilution can follow the trend of the TSI NPET but measure lower PN concentrations.

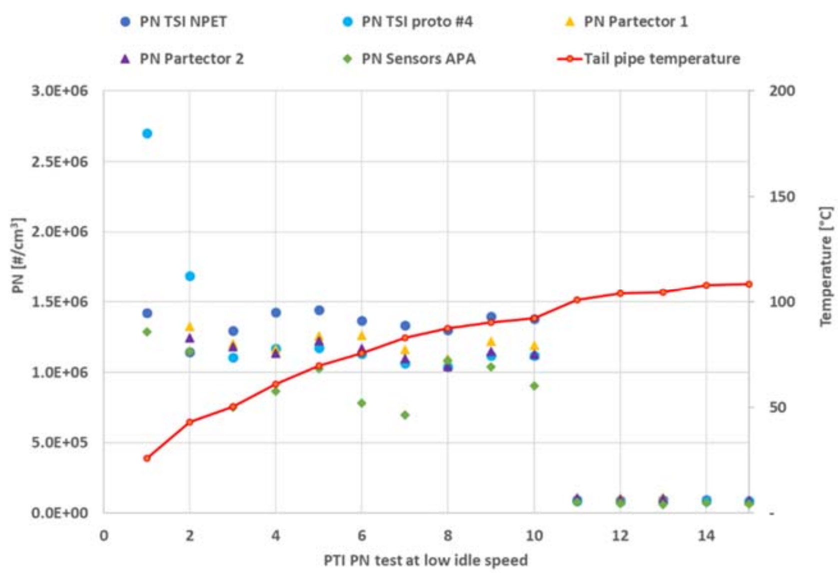

Figure 4-8: PN emission test results of low idle speed tests 1 – 15 with 5 PN-counters at low idle speed of VW Caddy Euro 6b diesel vehicle with DPF bypass, measured post DPF. The test was executed with an open DPF bypass and started with a cold engine.

In Figure 4-9 the PN emission measurement results of the warm PTI test of a Euro 6b VW Caddy with diesel engine and a DPF bypass is shown. The PN emission of the TSI-NPET has a decreasing trend in the 16 PTI tests, it starts at 94,457 and ends at 73,864 #/cm^3. Possibly this decreasing trend is caused by warming up of the engine. The TSI proto follows the trend of the TSI NPET but at a 7-10% lower level. The two Partectors show a less constant behaviour (compared to the TSI NPET). Initially the deviations were up to 20% but after the longer conditioning trip of PTI test 19 deviations were 324 and 224% and with lowering tail pipe temperatures the deviations reduced. Possibly, the lack of sample conditioning and the lack of a VPR are the cause of these fluctuating deviations. The Sensors APA measures PN emissions which are up to 42% lower than the TSI NPET and the deviations are not constant. Possibly the lack of sample conditioning and the lack of a VPR are here also the cause of these fluctuating deviations.

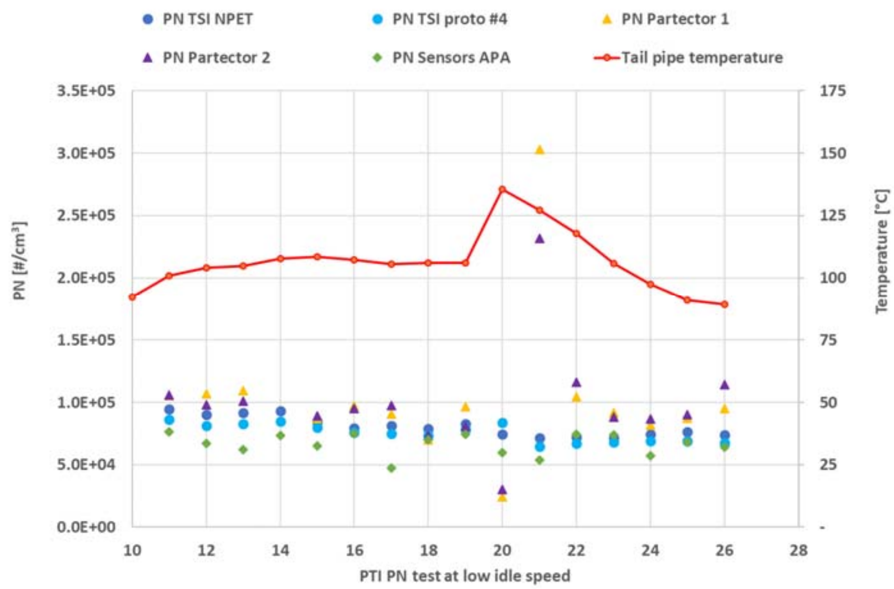

Figure 4-9: PN emissions of low idle speed test 10 – 26 with 5 PN-counters at low idle speed of a VW Caddy Euro 6b diesel vehicle with DPF bypass, measured post DPF. The test was started with an open DPF bypass and a warm engine. Before PTI test 20 the vehicle was warmed up in a relative long road trip.

4.4 EGR system investigations of light duty diesel vehicles

In several low idle speed tests EGR systems often appeared to be in different positions. In order to get a better view on EGR system behaviour different vehicles were tested at low idle speed and the behaviour of the EGR actuator (or valve) was logged with a diagnostic tester (Autel). The tests were started with a cold engine and the engines were warmed up when running at low idle speed. Then a snap acceleration was performed and the EGR system behaviour logged.
Special attention was given to the position of the EGR valve after the snap acceleration and the way of closure. The PN emissions were measured with a prototype TSI PTI tester without VPR.

Test results:
In Appendix D test results of EGR actuator valve behaviour of 9 vehicles are reported. The PN emissions at low idle speed of 7 vehicles was less than 1,000 #/cm^3, vehicle eight emitted 11,500 #/cm^3 and vehicle nine emitted 90,000 #/cm^3.

The position of the EGR valve actuators from 8 out of 9 Euro 4,5 and 6 diesel vehicles with DPF could be read with the Autel diagnostic tester. After a snap acceleration the EGR valve actuators of all 8 vehicles were opened and after 45 to 600 seconds running at low idle speed 5 out of 8 EGR valve actuators were fully closed. From the residual 3 vehicles the EGR valve actuators were opened for at least 900 seconds.

When EGR valve actuators closed, this happened in five cases abruptly, one valve closed gradually in a time period of 600 seconds.

Vehicles with different Euro classes from one brand have a very different behaviour, so the EGR dosing strategy is not typical for a certain brand.
The EGR valve actuators of all vehicles can be actively closed with the Autel diagnostic tester.

Euro 6 diesel vehicles often are equipped with a low and high pressure EGR system and have two EGR valve actuators. In case of the Euro 6 VW Caddy the PN emission pre-DPF with activated EGR systems is up to 15 million #/cm^3 and in case of closed EGR valves the PN emission pre DPF is 2 million #/cm^3.

The Euro 6b VW Caddy with DPF bypass was tested in consecutive low idle speed tests which all started with a snap acceleration. In Figure 4-10 the PN emission of repetitive idle tests followed by snap accelerations are shown. After most snap accelerations the PN emission drops immediately but in some tests the PN emission stays for a certain time at a higher level. From this test and the tests of the vehicles of Appendix D it is clear that snap engine accelerations result in a non-repeatable engine emission behavior.

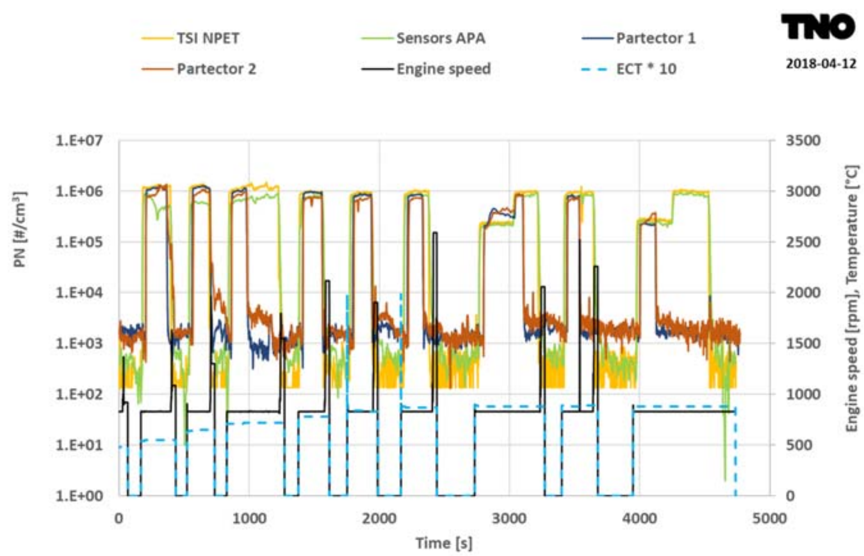

Figure 4-10: PN emissions of repetitive idle tests followed by snap accelerations of a VW Caddy Euro 6b with DPF bypass, 2018-12-04

4.5 PN emissions of heavy duty vehicles with DPF

The development of the PTI PN test procedure has been mainly done with light-duty vehicles. However DPF's of heavy-duty vehicles are similar to light-duty vehicles and therefore some tests with heavy-duty vehicles were performed. For screening of the performance of diesel particulate filters of heavy duty vehicles, recently a test is added to the Dutch in-service emissions testing programme [3] which uses a particle counter to measure the particle concentration at a stationary test in the exhaust tail pipe at two engines speeds; idle (500-600 rpm) and 'high' speed (1500-2000 rpm). Additionally, the local ambient particle concentration is measured. The measurements are conducted when the vehicle is prepared for other emission tests. For the measurement the NPET instrument of TSI is used.

Measurements conducted on five in-use heavy duty vehicles show particle numbers concentrations at given engine speeds under no load conditions to be below concentrations found in the ambient air. This indicates that very probably tested vehicles have properly functioning particle filters.

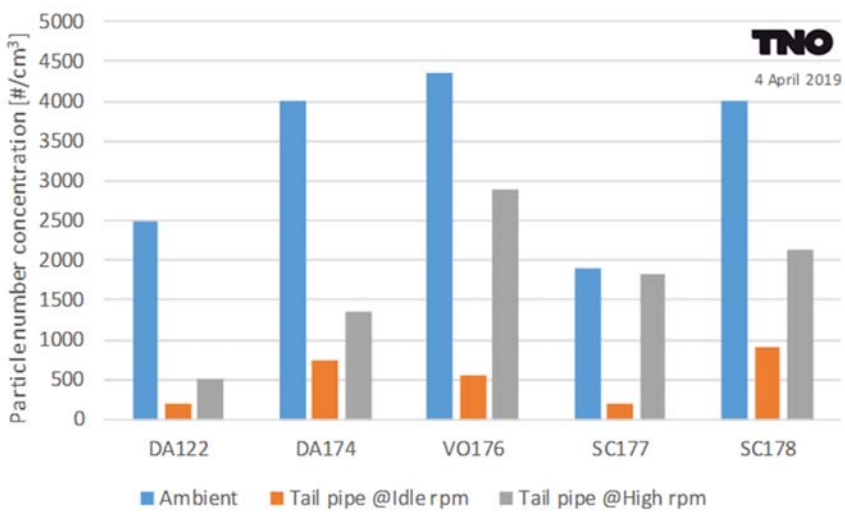

Figure 4-11: Particle number concentration measured at a stationary test in the ambient air and in the tail pipe of Euro VI trucks at low and high idle engine speed and under no load conditions.

4.6 PN emissions of gasoline direct injected vehicles without GPF

PN emissions of gasoline direct injected engines (GDI) are point of concern because they are higher than PN emissions of most port fuel injected (PFI) or indirect injected engines and higher than diesel vehicles with DPF. For future application of the PTI-PN emission test for, possibly all, gasoline engines and especially determination of the PTI-PN limit value detailed knowledge of PN emissions at idle speeds is needed. In this section basic PN measurements of gasoline engines without GPF (gasoline particle filter) are reported.

In Table 4-1 and Appendix E the PN emissions at idle speeds of three GDI vehicles without GPF are shown. At low idle speed the PN emission of cold engines are 1.7 to 5.0 * 10^5 #/cm^3 and warm engines emit 5 * 10^4 to 1.0 * 10^5 #/cm^3.
The PN emission of warm engines at high idle speed is 1.5 * 10^5 to 8 * 10^6 #/cm^3.

The PN emissions of the three vehicles show the same clear trends, these are:
- Cold engines at low idle speed have a higher PN emission than warm engines.
- At high idle speed the PN emission is substantial higher than at low idle speed.

Table 4-1: PN emissions of GDI vehicles without GPF at low and high idle speed

Vehicle	Odometer [km]	Euro class	PN [#/cm^3] Low idle cold	PN [#/cm^3] Low Idle warm	PN [#/cm^3] High Idle warm
Peugeot 5008	110,252	5	3.5 * 10^5	5.0 * 10^4	2 - 8 * 10^6
Ford Focus	139,952	5	5.0 * 10^5	6.0 * 10^4	1.5 * 10^5
Peugeot 308 1	20,189	6b	1.7 * 10^5	1.0 * 10^5	1.0 * 10^6

Some types of Euro 6d-temp passenger gasoline vehicles are not equipped with a GPF. For the development of future PTI-PN emission tests it is strongly advised to investigate these group of gasoline vehicles separately.

4.7 PN emissions of gasoline vehicles with GPF

Euro 6d-temp gasoline vehicles are mostly equipped with a GPF. For future application of the PTI-PN emission test with gasoline engines with GPF and especially determination of the PTI-PN limit value detailed knowledge of PN emissions of engines and filtration behaviour of GPF's at idle speed is needed.

In Table 4-2 and Appendix F the pre GPF PN emissions at idle speeds of two GDI vehicles are shown. At low idle speed the pre GPF PN emission of the cold engines are 3.0 to 6.6 * 10^6 #/cm^3 and warm engines emit 1 * 10^5 to 5.8 * 10^6 #/cm^3. The PN emissions of warm engines at high idle speed are 2.4 * 10^5 and 1.0 * 10^5 #/cm^3.

Table 4-2: PN emissions pre GPF of Euro 6d-temp gasoline vehicles at low idle speed. No pre-GPF measurements were performed with Ford Fiesta 1.

Vehicle	Odometer	PN [#/cm^3]	PN [#/cm^3]	PN [#/cm^3]
	[km]	Low idle	Low idle	High Idle
		cold	warm	warm
Ford Fiesta 1	15,707	-	-	-
Ford Fiesta 2	20,440	3.0 * 10^6	1.0 * 10^5	2.4 * 10^5
Peugeot 308 2	69,931	6.6 * 10^6	5.8 * 10^6	1.0 * 10^5

The pre GPF PN emissions of the two tested vehicles show the next trends:

- Cold engines at low idle speed have higher or similar PN emissions than warm engines.
- At high idle speed the PN emission of the Ford Fiesta is higher than at low idle speed. However the Peugeot 308 has at high idle speed lower PN emissions than at low idle speed.

In Table 4-3 and Appendix F the post GPF PN emissions at idle speeds of three GDI vehicles are shown. At low idle speed the post GPF PN emission of the cold engines are 6.2 * 10^4 to 1.0 * 10^6 #/cm^3 and warm engines emit 1.0 * 10^3 to 1.2 * 10^4 #/cm^3. The PN emission of warm engines at high idle speed is 1.0 * 10^1 and 1.4 * 10^4 #/cm^3.

Table 4-3: PN emissions post GPF of Euro 6d-temp gasoline vehicles at idle speeds

Vehicle	Odometer	PN [#/cm^3]	PN [#/cm^3]	PN [#/cm^3]
	[km]	Low idle	Low idle	High Idle
		cold	warm	warm
Ford Fiesta 1	15,707	6.2 * 10^4	1.2 * 10^4	-
Ford Fiesta 2	20,440	2.0 * 10^5	4.0 * 10^3	1.4 * 10^4
Peugeot 308 2	69,931	1.0 * 10^6	1.0 * 10^3	1.0 * 10^1

The post GPF PN emissions of the three tested vehicles show the next trends:

- Cold engines at low idle speed have higher PN emission than warm engines.
- At high idle speed the PN emission of the Ford Fiesta 2 is higher than at low idle speed. However the Peugeot 308 has at high idle speed lower PN emission than at low idle speed.

5 Proposal for a diesel particulate filter test with a particle counter in the PTI

The Dutch research activities of a PTI test procedure for checking Diesel Particulate Filters have been started in 2012 and as a results of the research activities [1], [3], [5], [6] and [7] a proposal for a diesel particulate filter test with a particle counter is defined.

In Appendix G a very detailed description and background information of this PTI-PN test procedure is given. The test procedure is also expressed in a flow chart, see Figure 5-1.

This PTI-PN test procedure is developed for diesel vehicles with a DPF. For gasoline vehicles more research is needed for determination of a PTI emission test and PN limit values.

Due to the commonly very high filtration efficiencies of DPF's the test procedure at low idle speed can be started without engine conditioning because it is expected that even in these less favourable conditions most vehicles will pass the PTI-PN test. In case of a fail the next conditions must be realised::

- The engine must be warmed up, i.e., the coolant temperature should be higher than 70 °C.
- The EGR actuator valve must be closed.
- DPF regenerations must be avoided.

The PTI PN limit values are linked to the type approval PM or PN limit values of the Type 1 test of the vehicle. The Type 1 test is the NEDC test on the chassis dynamometer.

It is expected that 90% of the tested vehicles will pass the defined test in 30 seconds. For the failed vehicles additional preconditioning of the engine is needed and this will lead to an extension of the test procedure by a few minutes.

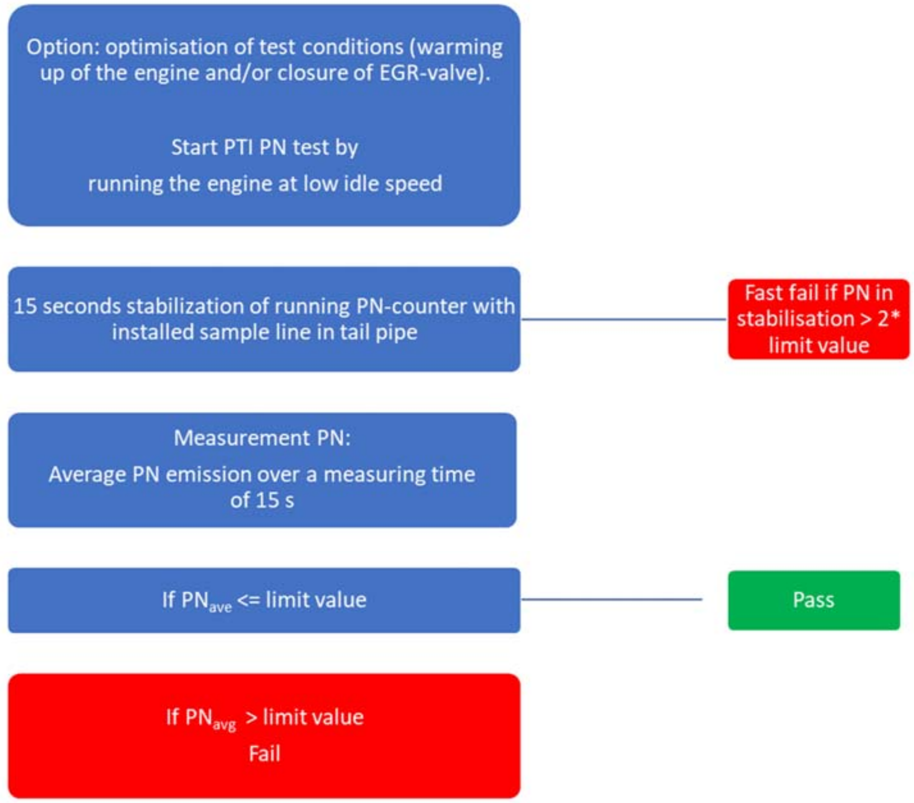

Figure 5-1: Flow chart Dutch PTI PN test procedure for diesel vehicles.

6 Conclusions

With the introduction of the wall flow diesel particulate filter (DPF) in 2000, diesel cars have become much cleaner than the older petrol- and diesel cars. Euro 4-6 diesel vehicles reduce the PM emissions by a factor 20-40, compared to vehicles without a DPF. Currently the latest gasoline vehicles are also equipped with a particulate filter. In this study PN emissions of diesel and gasoline vehicles were investigated under PTI conditions and a new PTI-PN test procedure for diesel vehicles was defined.

PTI PN emissions of diesel vehicles without DPF:
The PN emission of the tested vehicles at low idle speed of cold engines without DPF is higher than warm engines and at high idle speed the PN emission is higher than at low idle speed. These measured emission trends deviate from former tested very old diesel vehicles with very high mileages.
PN emissions at low idle speed of six warm Euro 3 diesel engines without DPF were 2 to 9.4 million #/cm^3 and thirteen Euro 4 vehicles without DPF emitted 1.0 to 10 million #/cm^3.

PTI PN emissions of diesel vehicles with DPF:
The PN emission at low idle speed of warm engines with DPF are often less than 5,000 #/cm^3 and lower than the PN concentration of ambient air. Defects of DPF's result immediately in a substantial increase of the PN emission at low idle speed and this behavior is the basis for a PTI-PN test.

PN emissions of diesel vehicles during warming up of the engine:
After a cold start of a diesel vehicle with DPF in good condition the PN emission can be relatively high (>250,000 #/cm^3). However after warming up of the engine the PN emission can be less than 5,000 #/cm^3. As a result of the warming up behavior of a diesel vehicle with DPF the easiest condition to pass PTI test is a warm engine.

PN emissions and EGR strategies of diesel engines:
The application of EGR can increase the PN emission of an engine at low idle speed with a factor more than 10. This may increase the post DPF PN emission as well. In order to create the easiest test conditions to pass the PTI test the EGR actuator valve must be closed. Furthermore snap accelerations in a PTI test may lead to the opening of the EGR valve and make it more difficult to pass the PTI test. Moreover, a test in which it is permitted that the EGR valve is closed, does not lead to diesel cars with a manipulated EGR valve having an improper advantage.

Conditioning of EGR systems in the PTI test:
The application of EGR increases the PN emission of engines at low idle speed from 1-2 to 10-15 million #/cm^3. In order to create similar test conditions for DPF's of all vehicles in PTI tests, the most feasible defined engine condition is an EGR system with closed EGR actuator valve because in this condition the PN emission of the engine is the lowest and is approximately 1-2 million #/cm^3. For most vehicles at low idle speed the EGR valve actuator closes after a certain time.
For other vehicles EGR valves can be closed with a diagnostic tester. Consequently manipulation of the PTI test is prevented because the test is executed with the lowest PN emission of the engine.

Snap accelerations in test procedure:
Snap accelerations followed with low idle speed operation seem to result in a non-defined engine behaviour because in consecutive tests the EGR valve will be activated/opened and after a certain non-repeatable time closed. Practically this results in varying stabilisation times of the PTI test and this should be avoided in a test procedure.

On Board Diagnostics performance and high PN emissions:
Three out of twenty four tested vehicles with DPF had very high PN emissions at low idle speed (3.9 - 5.3 * 10^6 #/cm^3) and only one of the three high emitters had an active emission related OBD fault code. This indicates that OBD systems are not well designed to detect DPF failures.

PN emissions of HD vehicles:
Euro VI trucks have similar PN emission behaviour as light duty diesel vehicles with DPF and consequently the PTI PN test can be applied for trucks and buses with DPF's.

PN limit values in the PTI:
The former proposed PTI PN limit value of 250,000 #/cm^3 at low idle speed seem to be a reasonable value for all tested Euro 5b, 6 and VI diesel vehicles. For Euro 3, 4 and 5a vehicles with DPF a PTI PN limit value of 1,000,000 #/cm3 is proposed.

PN emissions of direct injected gasoline vehicles without GPF:
The PN emissions of the tested vehicles show clear trends, these are:

- Three cold GDI engines at low idle speed have approximately 10 times higher PN emissions (1.7 to 5.0 * 10^5 #/cm^3) than warm engines which emit 1 to 6 * 10^4 #/cm^3.
- At high idle speed the PN emission of the GDI engines is 1.5 * 10^5 to 8 * 10^6 #/cm^3 and this is 15 – 130 times higher than the PN emission at low idle speed.

PN emissions of direct injected gasoline vehicles with GPF:
Tail pipe PN emissions at low idle speed of the three warm tested GDI vehicles with GPF are comparable and in the range of 1,0 * 10^3 to 1,2 * 10^4 but just after a cold start they can be 5 - 1000 times higher. However the engine out PN emission (pre GPF) of two tested vehicles at low idle speed are not comparable and are 1.0 * 10^5 and 5.8 * 10^6 #/cm^3.

Performance of prototype PTI PN testers:
Prototype PTI PN testers sometimes are in line with a certified PN tester (TSI 3795) but can also deviate up to more than 300%. A lack of sample conditioning and the absence of a volatile particle remover (VPR) seem to be the major reasons for the measured PN deviations.

PTI-PN test procedure for diesel vehicles:
The research activities of last years resulted in a proposal for a particulate filter test PTI test procedure for diesel vehicles with DPF with a particle counter. It contains three elements which are: an emission test at low idle speed, a specification of a particle counter and a PTI-PN limit value which is described in Appendix G.

The flow chart of the PTI-PN emission test is reported in Figure 6-1. For most vehicles this test procedure can be executed in 10-30 seconds.

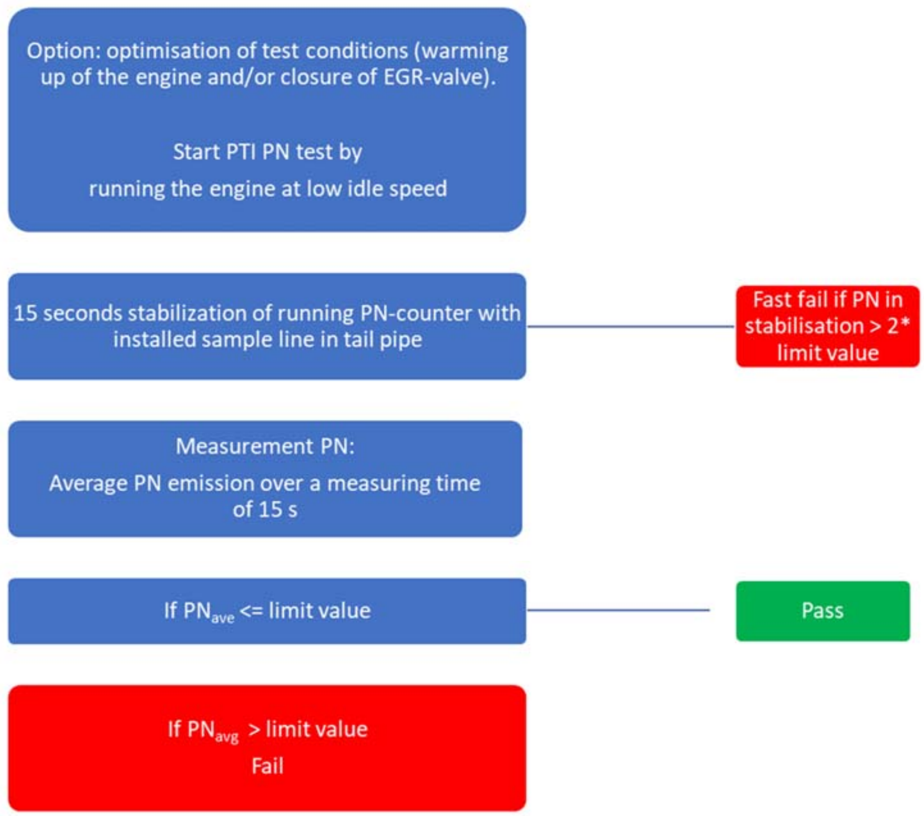

Figure 6-1: Flow chart Dutch PTI PN test procedure for diesel vehicles. For most vehicles the test procedure can be completed within 10-30 seconds.

PTI-PN test procedure for gasoline vehicles:
First investigations of PN emission behaviour of GDI vehicles without and with GPF show specific PN emission behaviour. For development of a PTI-PN test procedure for gasoline vehicles further research and development is needed.

7 Recommendations

First investigations of PN emissions of direct-injection gasoline vehicles and GPF's show PN emission trends which are not in line with the PN emission behaviour of diesel vehicles with DPF. It is recommended to investigate the PN emissions of different gasoline vehicles with GPF and their specific emission behaviours.
After studying these results possibilities for simple PTI test can be investigated. The PTI-PN tester as specified for testing of particulate filters of diesel vehicles is expected to be suitable for gasoline vehicles too.

8 Acknowledgements

Acknowledgments go to the equipment manufacturers TSI GMBH in Aachen Germany, Naneos Particle Solutions GMBH in Windisch Swiss, and Sensors Europe GMBH in Erkrath Germany which provided their prototype particulate counters for testing in the Dutch in-service emission test program.

Furthermore acknowledgements go to the next automotive companies:
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Finally acknowledgements go to the Ministry of Infrastructure and Water Management that funds the test program.

9 Abbreviations

APK	Algemene Periodieke Keuring (Dutch PTI)
CPC	Condensation Particle Counter
CVS	Constant Volume Sampler
DC	Diffusion Charger
DI	Direct Injection
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
EOBD	Electronic On Board Diagnosis
GDI	Gasoline Direct Injection
GPF	Gasoline Particulate Filter
HD	Heavy Duty
ISC	In Service Conformity
LD	Light Duty
MIL	Malfunction Indication Light
NEDC	New European Driving Cycle
NO_x	Nitrogen Oxides ($NO + NO_2$)
PM	Particulate Matter
PMP	Particulate Measurement Programme
PN	Particulate Number
PTI	Periodic Technical Inspection
SCR	Selective Catalytic Reduction
TWC	Three Way Catalyst
VERT	Verification of Emission Reduction Technologies
VPR	Volatile Particle Remover

10 References

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11 Signature

The Hague, 13 January 2020	TNO
Peter van der Mark Projectleader	Gerrit Kadijk Author

A PN emissions of diesel vehicles without DPF

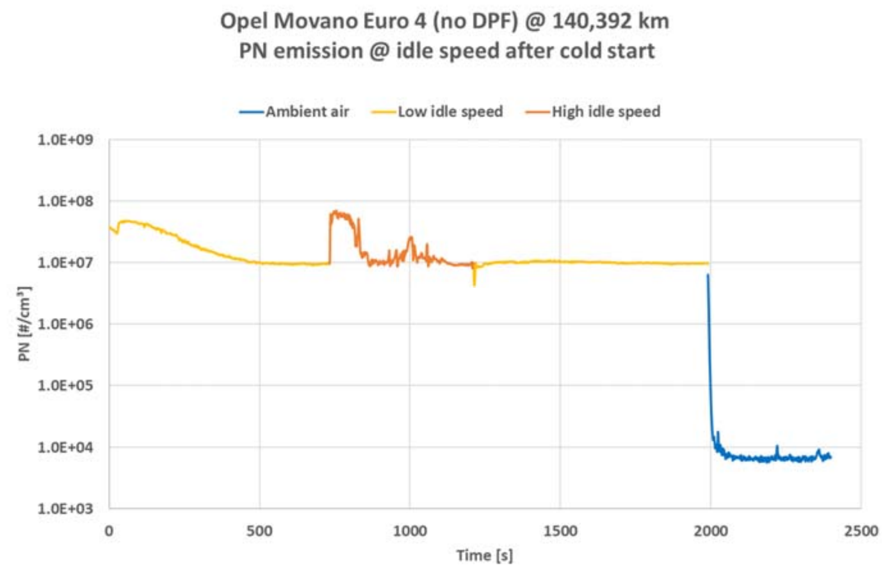


Figure A-1: PN emissions at low and high idle speed after a cold start of a Euro 4 Opel Movano without DPF @ 140,392 km.

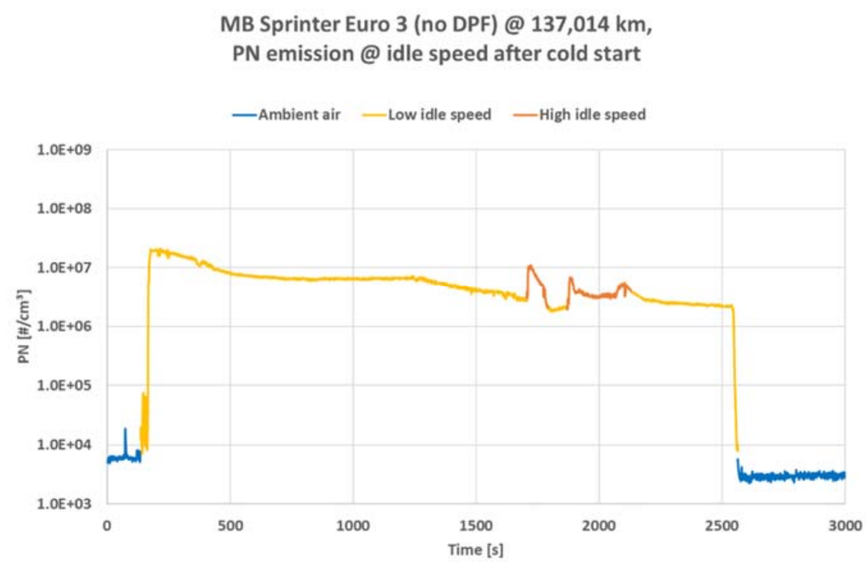


Figure A-2: PN emissions at low and high idle speed after a cold start of a Euro 3 Mercedes Sprinter without DPF @ 137,014 km.

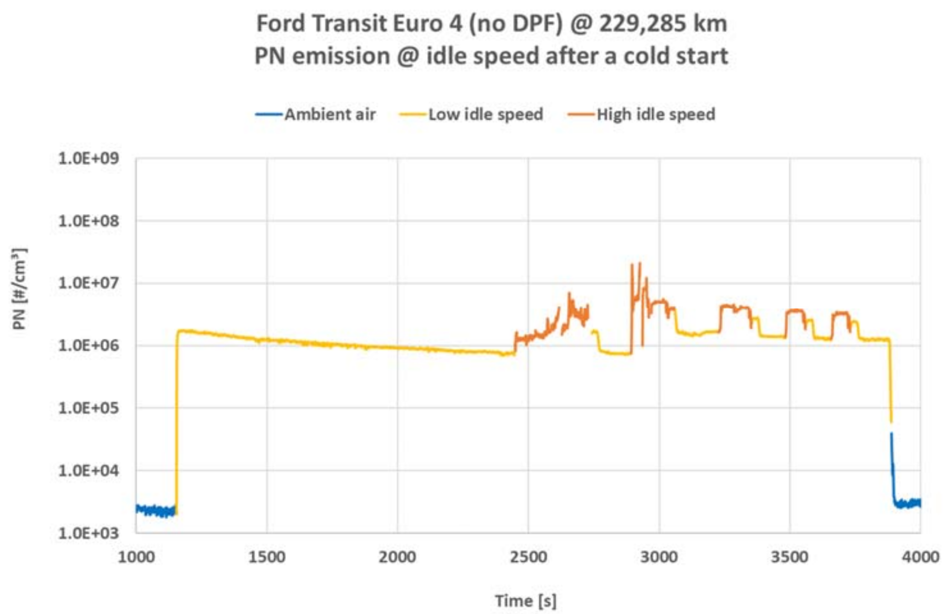


Figure A-3: PN emissions at low and high idle speed after a cold start of a Euro 4 Ford Transit without DPF @ 229,285 km.

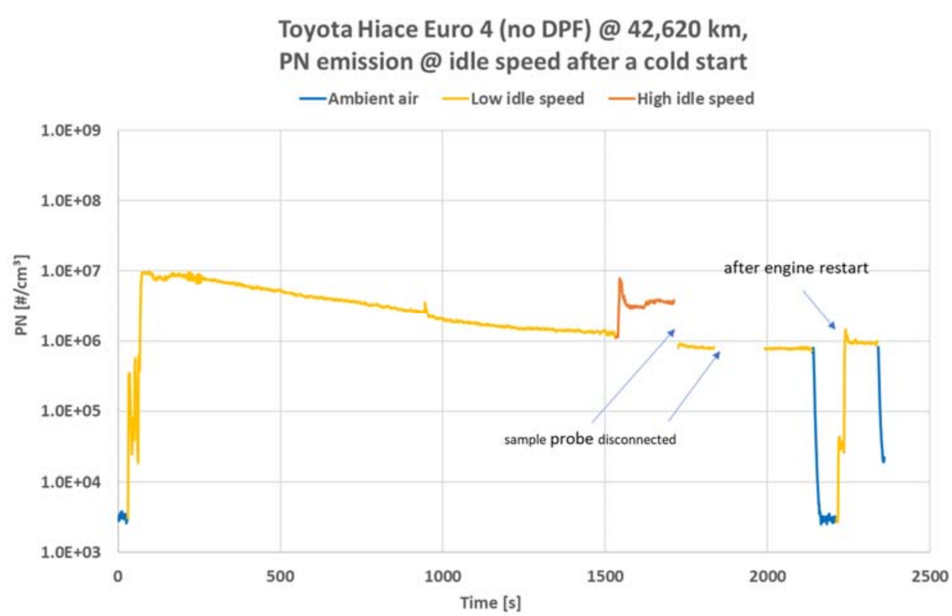


Figure A-4: PN emissions at low and high idle speed after a cold start of a Euro 4 Toyota Hiace without DPF @ 42,620 km.

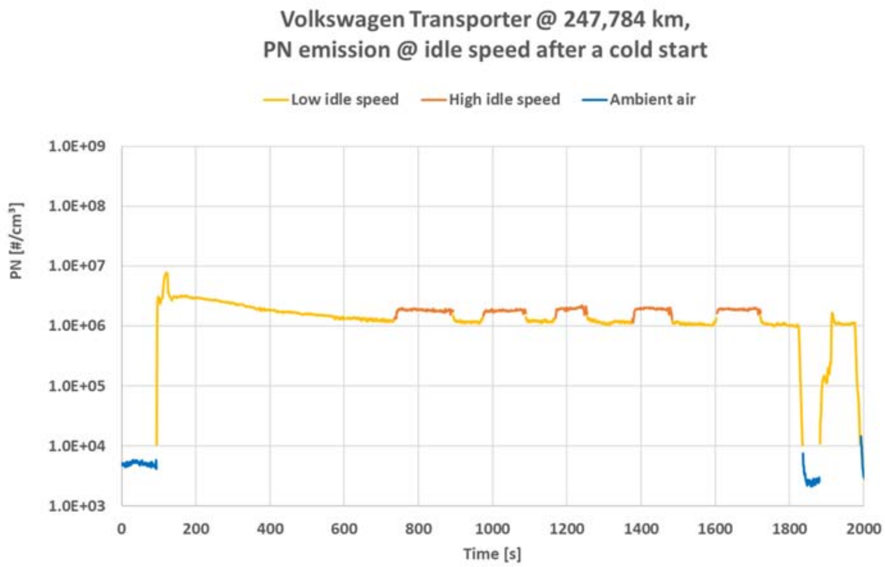


Figure A-5: PN emissions at low and high idle speed after a cold start of a Euro X VW Transporter without DPF @ 247,784 km.

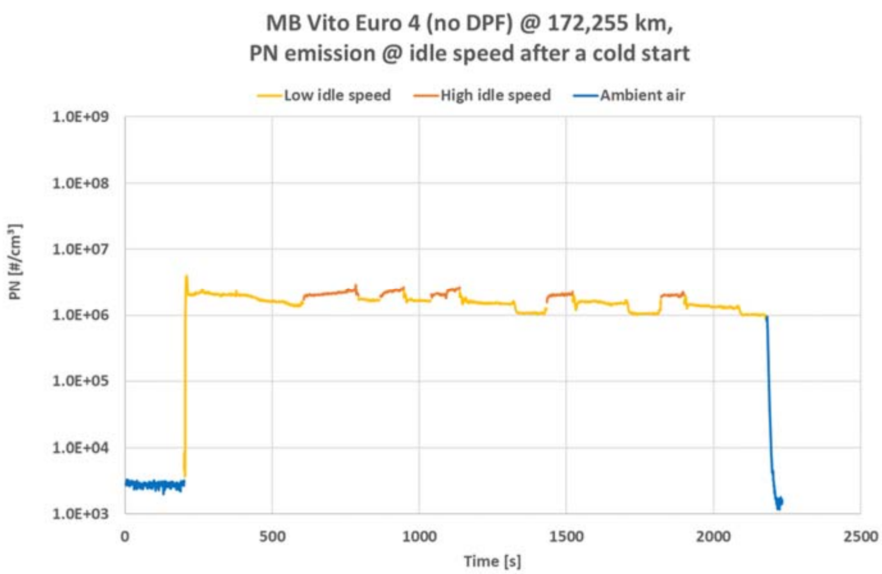


Figure A-6: PN emissions at low and high idle speed after a cold start of a Euro 4 Mercedes Vito without DPF @ 172,255 km.

B PN emissions of diesel vehicles with DPF

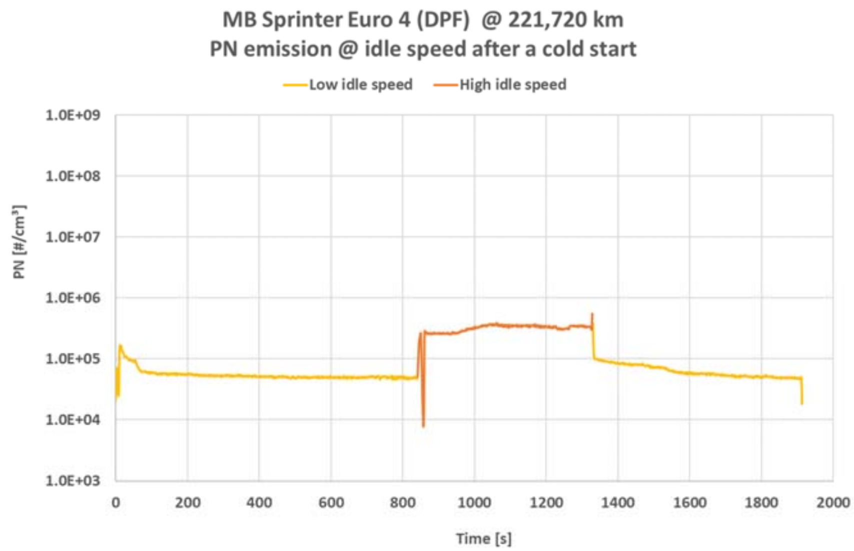


Figure B-1: PN emissions at low and high idle speed after a cold start of a Euro 4 Mercedes Sprinter with DPF @ 221,720 km.

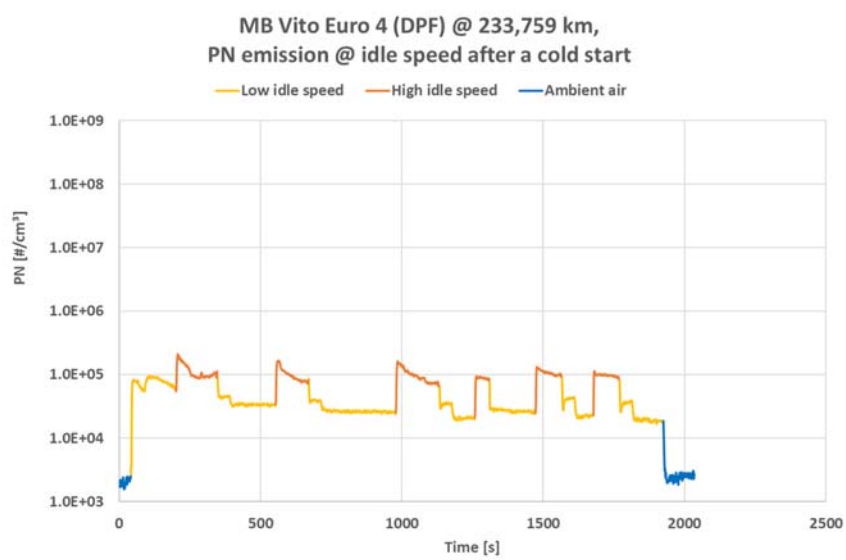


Figure B-2: PN emissions at low and high idle speed after a cold start of a Euro 4 Mercedes Vito with DPF @ 233,759 km.

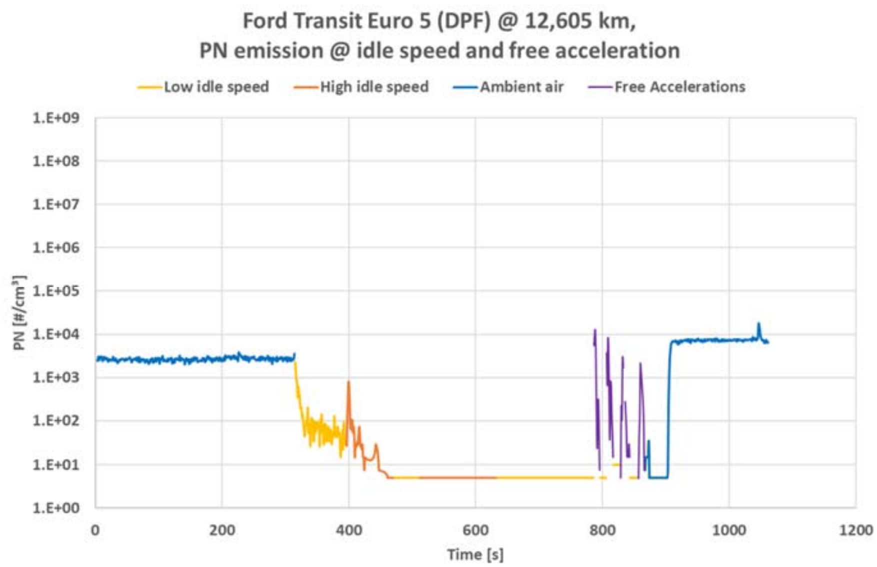


Figure B-3: PN emissions at low and high idle speed and free acceleration tests after a cold start of a Euro 5 Ford Transit with DPF @ 12,605 km.

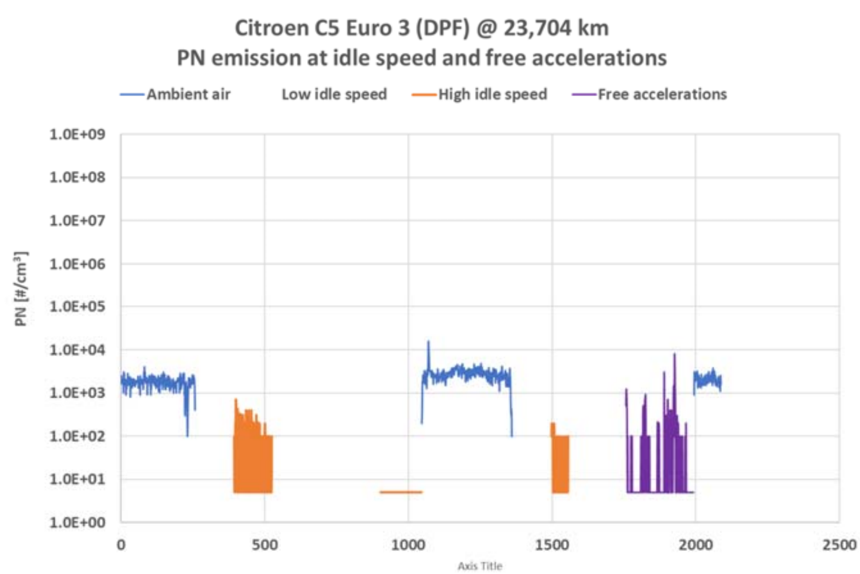


Figure B-4: PN emissions @ low and high idle speed and free acceleration tests after a cold start of a Euro 3 Citroen C5 with DPF @ 23,704 km.

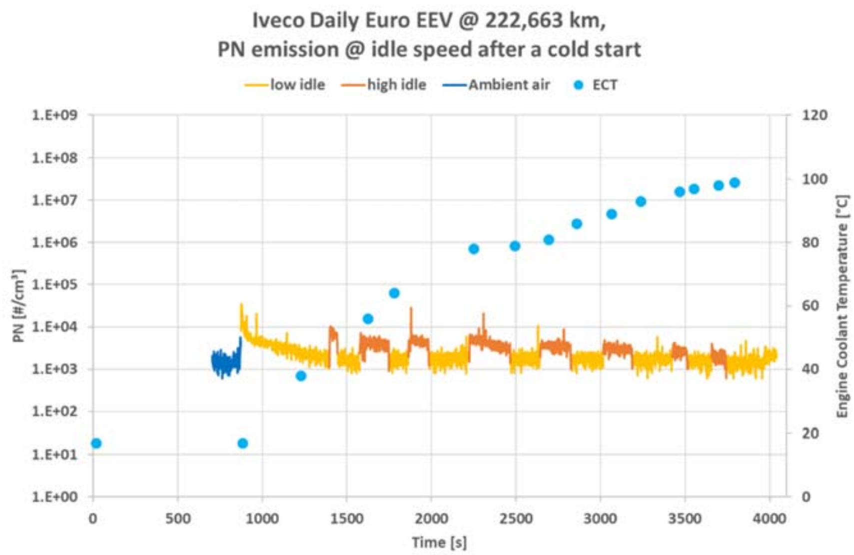


Figure B-5: PN emissions at low and high idle speed after a cold start of an EEV Iveco Daily with DPF @ 222,663 km

C OBD investigations diesel vehicles

OBD info PN-emission tests

Date:

Trade mark	Model	License	DET	Euro	Odometer	Visual DPF	Pending OBD codes	Stored OBD
		number	[dd-mm-yyyy]	class	[km]	[Yes/No]	Codes	Codes
-	-	-	-	-	-	-	-	-
MB	Vito	1VLF38	11-1-2011	5	233759	Y	-	P2453 (DPF pressure sensor A)
MB	Viano	95VZP4	3-2-2009	4	369040	Y	P0473 (exhaust pressure sensor high input)	P0670 (glow plug control module)
MB	Vito	93VBF7	18-10-2006	4	284834	Y	P0103 (mass air flow circuit high)	-
MB	Vito	54VVP1	14-1-2009	5	159459	N	-	-
Toyota	Hiace	2VJZ81	2-11-2010	4	247785	N	-	-
VW	Transporter	VL534F	10-5-2004	2	172255	N	-	-
MB	Sprinter	48VJS3	11-9-2007	3	194647	Y	-	-
VW	Crafter	4VSN56	6-1-2012	EEV	203556	Y	-	P2BAC (NOx exceedence deactivation of EGR)
MB	Sprinter	94VRN7	11-6-2008	4	313821	?	-	-
MB	Sprinter	6VPK99	7-7-2011	5	173842	N	-	P2BAC (NOx exceedence deactivation of EGR)
VW	Crafter	9VRR06	18-10-2011	EEV	183004	Y	P229F (NOx sensor sensor circuit) & P068A (ECM/PCM Power Ralay)	P2BA7 (Empty Reagent Tank)
MB	Sprinter	9VZD07	18-9-2012	EEV	191113	Y	-	P2BAC (NOx exceedence deactivation of EGR)
MB	Sprinter	9VSK71	5-5-2010	5	99619	Y	-	P2BAC (NOx exceedence deactivation of EGR)
Iveco	Daily	VB194S	5-1-2018	EEV	222663	Y	No OBD response	No OBD response
MB	Sprinter	4VKN29	12-11-2010	5	59059	Y	-	P2BAC (NOx exceedence deactivation of EGR)
MB	Sprinter	VG587H	14-1-2014	5	189242	Y	-	-
MB	Sprinter	6VPL20	26-5-2011	5	214528	Y	-	P0191 (fuel rail pressure sensor) & P2BAC (NOx exceedence deactivation of EGR)
MB	Sprinter	VL162R	25-3-2015	6	337888	Y	No OBD response	No OBD response
MB	Sprinter	VR924R	28-2-2003	2	61018	Y	-	-
MB	Sprinter	17VHL6	20-7-2007	4	510069	N	-	-
MB	Sprinter	9VZJ31	16-10-2012	EEV	329327	Y	-	P2BAC (NOx exceedence deactivation of EGR)
Ford	Transit	V029PG	26-8-2015	5	12605	Y	-	-
Peugeot	Boxer	63BTRJ	29-6-2005	3	279718	N	-	-
Iveco	Massif	17VXT2	2-12-2008	4	42620	N	-	P0110 (intake air temp) & P0100 (mass or volume air flow)
Opel	Vivaro	20BTZL	22-8-2005	4	288676	N	-	-
MB	Vito	22BXLX	1-1-2006	4	260000	N	-	-
Toyota	Hiace	86BSFK	3-2-2005	3	157761	N	No OBD response (Linking error)	No OBD response (Linking error)
VW	Kombi	31ZDT1	26-7-2011	5	214365	Y	-	-
Toyota	Dyna	6VGR51	3-3-2010	4	116053	N	-	-
Toyota	D4D	45VRX1	11-6-2008	4	122214	N	-	-

D EGR actuator valves investigations at idle speed

				EGR valve			PN post DPF low idle speed TSI PTI PN
Trade mark	Model	Odometer [km]	Euro class	External activation	Position readable	Automatic closure of EGR valve	[#/cm³]
VW	Caddy		6	Yes	Yes	No	0
VW	Polo	215,434	5	?	Yes	Yes, over 600 s the EGR closes gradually from 17.3% to 0.8%	11,500 & EGR valve pos 0.8%
Renault	Trafic	202,787	5	?	Yes	After 45 s the EGR closes abruptly from 16% to 0%.	0
Ford	Cmax	124,160	4	Yes	Yes	No	0
Audi	A6	112,590	5	Yes	Yes	No	100
VW	Transporter	59,548	5	Yes	Yes	After 300 s the EGR closes abruptly from 35% to 0%	1,000
Porsche	Macan	57,802	6	?	?	?	0
Volvo	V60 diesel hybrid	50,424	5	Yes	Yes	After 60 s the EGR valve closes abruptly from 31% to 0%	200
Peugeot	3008 diesel hybrid	108,720	5	Yes	Yes	After 300 s the EGR closes abruptly from 51% to 0%	90,000 & EGR valve pos 0%

E PN emissions of gasoline vehicles without GPF

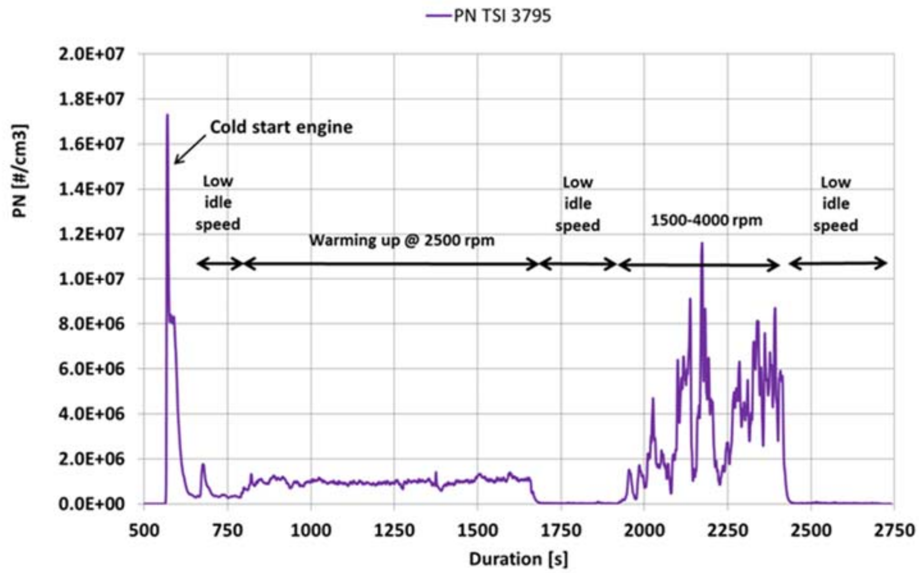


Figure E-1: PN emissions of a Peugeot 5008 1.6 ltr DI Euro 5 gasoline vehicle @ 110,252 km (1).

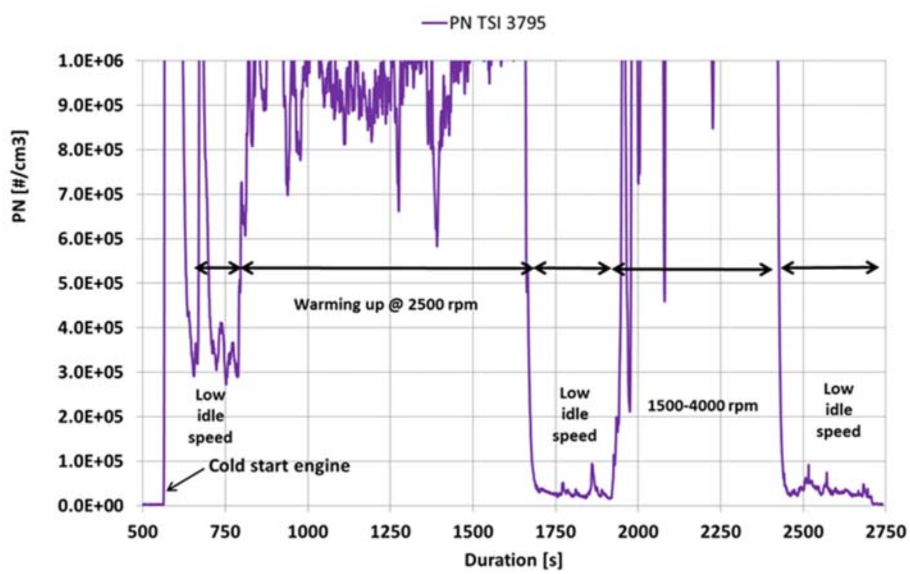


Figure E-2: PN emissions of a Peugeot 5008 1.6 ltr DI Euro 5 gasoline vehicle @ 110,252 km (2).

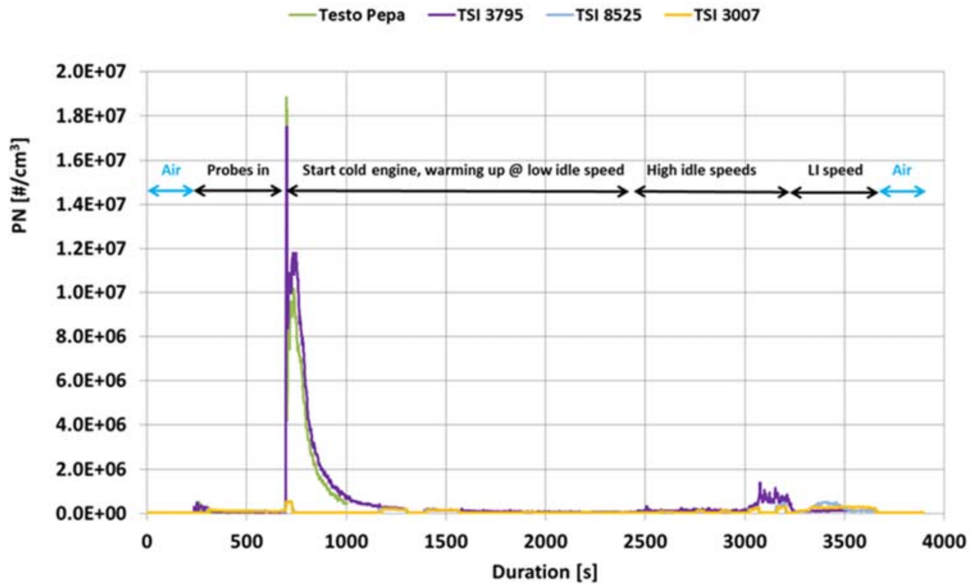


Figure E-3: PN emissions of a Ford Focus 1.6 ltr DI Euro 5 gasoline vehicle @ 139,592 km (1).

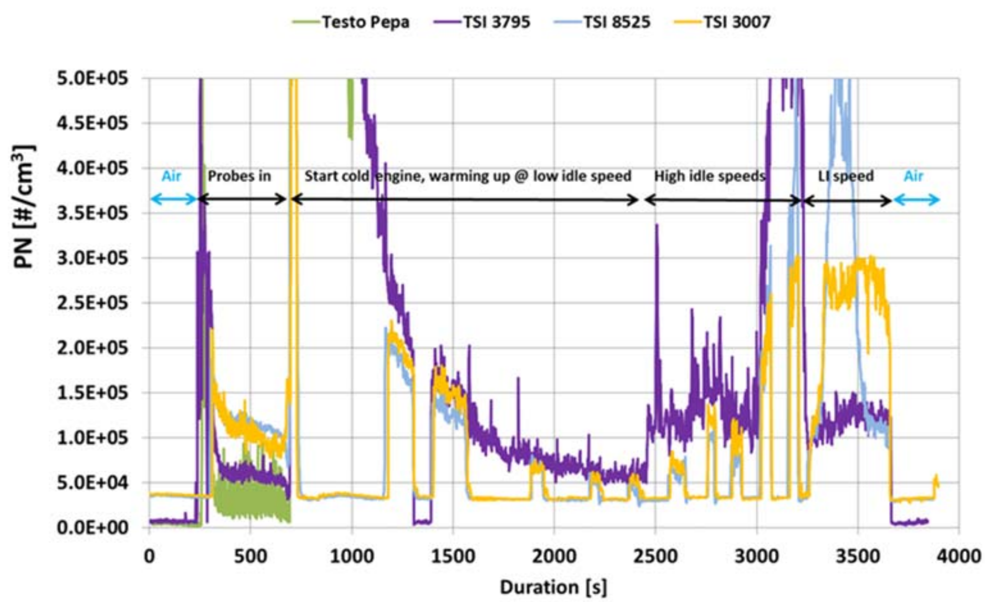


Figure E-4: PN emissions of a Ford Focus 1.6 ltr DI Euro 5 gasoline vehicle @ 139,592 km (2).

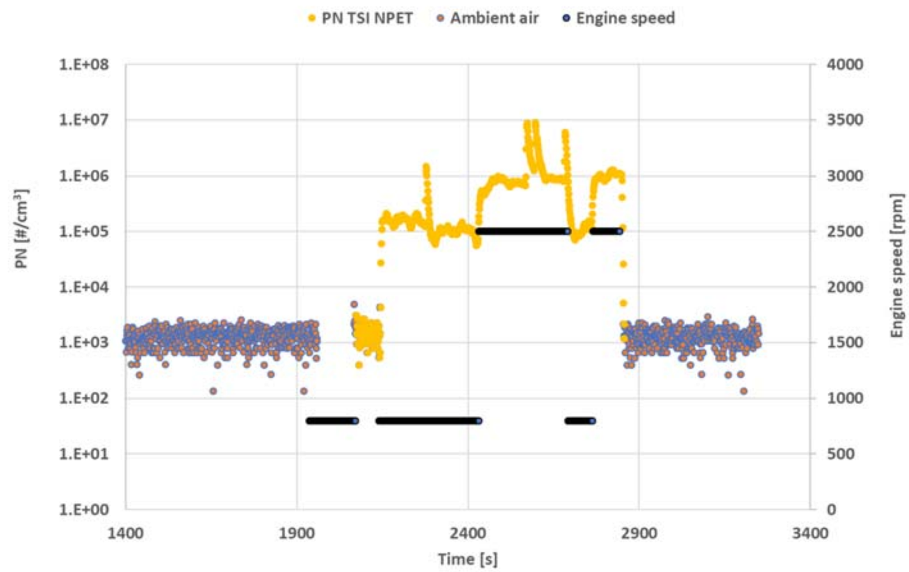


Figure E-5: PN emissions of a Peugeot 308 (1) Euro 6 gasoline vehicle @ 20,189 km.

F PN emissions of gasoline vehicles with GPF

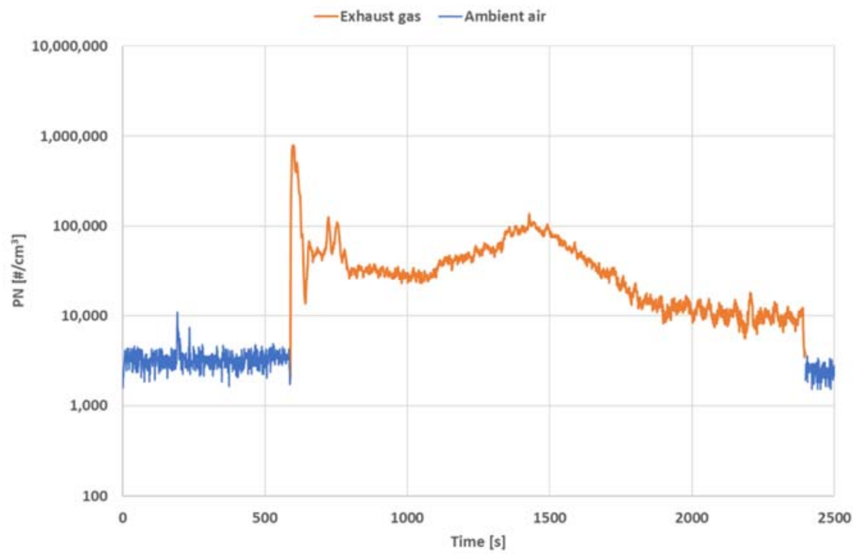


Figure F-1: PN emission of a Euro 6 Ford Fiesta (1) GDI vehicle with GPF. After the cold start at t=600 s, the engine was warmed up at low idle speed over a period of 1800 s.

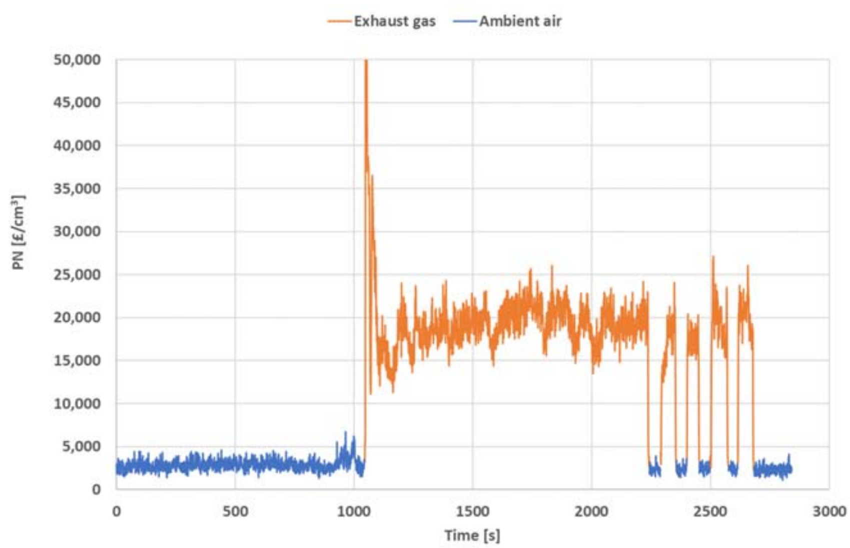


Figure F-2: PN emission of a Euro 6 Ford Fiesta (1) GDI vehicle with GPF. After the warm start @ t=1050 s, the engine run at low idle speed over a period of 1650 s. From t = 2250 to 2750 several times the sample probe of the PN counter was removed and reinstalled from the tail pipe.

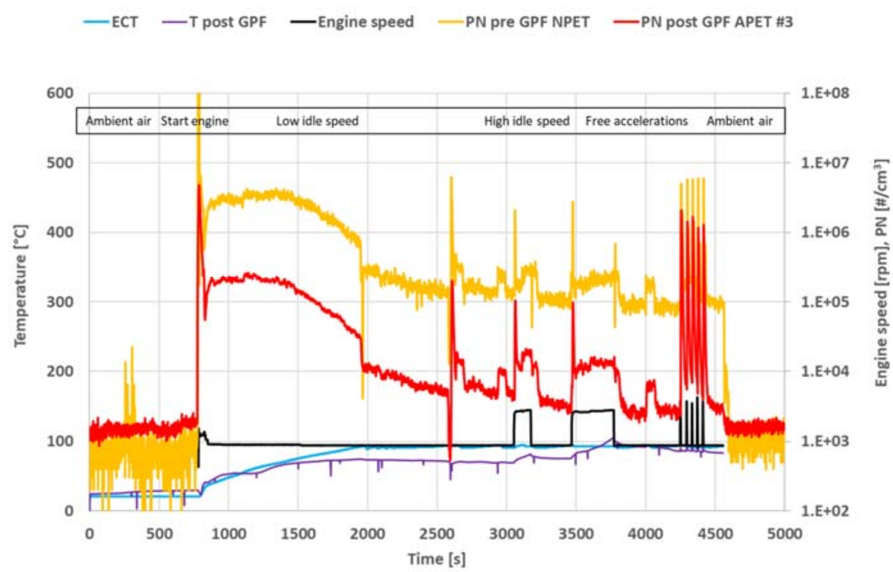


Figure F-3: PN emissions pre & post GPF at low and high idle speeds during warming up and free accelerations of a Ford Fiesta (2) Euro 6d-temp gasoline vehicle.

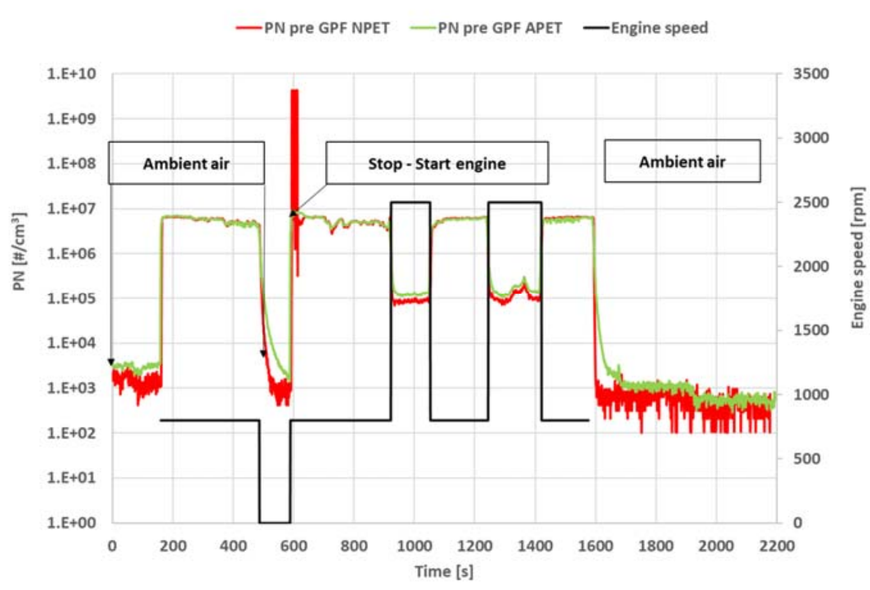


Figure F-4: PN emissions pre GPF at low and high idle speeds during warming up of a Peugeot 308 (2) Euro 6d-temp gasoline vehicle.

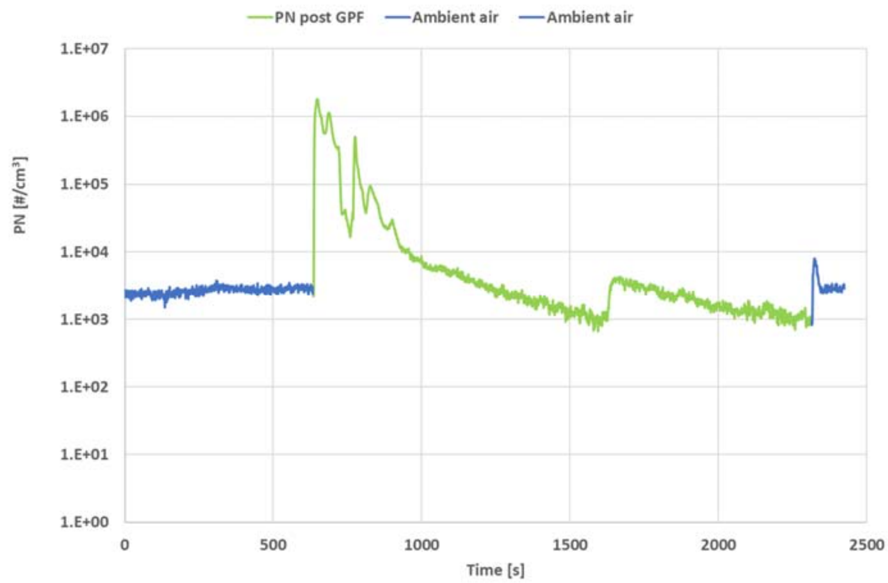


Figure F-5: PN emission post GPF after a cold start and during warming up at low idle speed of a Peugeot 308 (2) Euro 6d-temp gasoline vehicle.

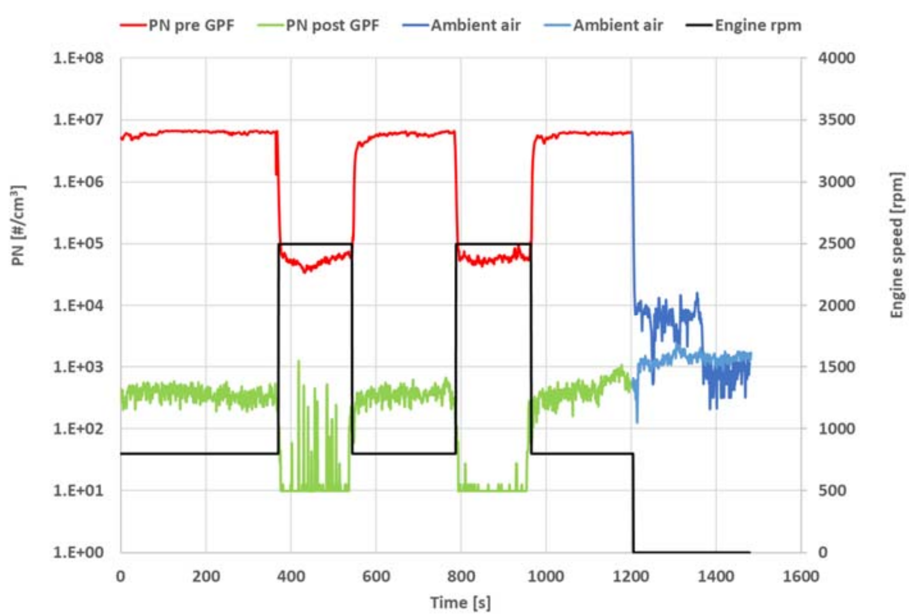


Figure F-6: PN emissions pre & post GPF at low and high idle speeds of a warm engine of a Peugeot 308 (2) Euro 6d-temp gasoline vehicle.

G Proposal for a particulate filter test with a particle counter in the Netherlands Periodic Technical Inspection

■ Content:

1. Introduction

Application of diesel particulate filters (DPFs) has decreased the particulate emission of diesel vehicles to a very low level. In the Netherlands there is no appropriate DPF test currently available for the periodic technical inspection (PTI). The Netherlands therefore intends to introduce a DPF test in the PTI. A new particulate number (PN) based PTI test procedure has been developed by the research organization TNO, the Netherlands Vehicle Authority RDW, the Netherlands Metrology Institute NMi and the Ministry of Infrastructure and Water Management. The test is executed at low idle speed with a particulate counter.

The introduction of a DPF test is part of the Netherlands' plan of action for particulate filters. As the first step of this plan, the new particle test will be available in 2019 at RDW inspection stations. The police will then be given the opportunity in 2019 to check particulate filters with a particle counter at roadside inspections (RSI). Finally, the particle counter test will be introduced for checking DPFs in the Netherlands' PTI. In view of the required preparation time for RDW and the car workshops in the Netherlands, the target date for this is 2021.

Note: This PTI-PN test procedure is not developed for Gasoline Particulate Filters (GPF) in the PTI. For checking GPF's in the PTI this test procedure needs to be further developed and revised. Main attention must be paid to the PTI emission test for GPF's and feasible PTI PN limit values. It is expected that the PTI-PN-tester can be used unmodified.

2. Objective

This document aims to describe an emission test procedure for the Periodic Technical Inspection (PTI) and Road Site Inspection (RSI) in order to assess the condition of diesel particulate filters (DPFs) by a particulate number test and to propose pass/fail criteria.

The method for measuring the number of particles in the exhaust of a car has been developed by an international working group (VERT-NPTI), in which the Netherlands participates with representatives of TNO, NMi, RDW and the Ministry of Infrastructure and Water Management. In addition to the Netherlands, Switzerland, Germany, Belgium, the European Commission (JRC) and various manufacturers of particle counters were represented in the working group.

The working group has established the technical specifications of a particle counter for direct use in the exhaust of a car. The working group also discussed the precise manner in which the particle measurement must be carried out, as well as the limit value for the number of particles per cubic centimeter to pass the test.

3. Test equipment

The specifications for this new measuring instrument have been drawn up by NMi in consultation with manufacturers of particle counters. The relevant specifications have been laid down by NMI in an English-language document. Germany proposed global harmonization of PTI particulate counter specifications within the framework of the International Organization for Legal Metrology (OIML). The German metrology institute PTB (Physikalisch-Technische Bundesanstalt) and NMi have taken on the task of initiating this global harmonization.

A Particulate Number (PN) tester measures the volumetric PN concentration (solid particles) in the tail pipe. The main characteristics of the PN-tester, as described in the document with the draft specifications, are as follows:

- Applicable for diesel and gasoline engines.
- The tester contains a sampling system, a volatile particle remover (VPR) and a PN-counter.
- The tester is characterized with particle sizes of 23, 50 and 80 nm.
- The volatile particle remover has an efficiency of more than 95%.
- Particle size for calibration and linearity check is > 50 nm.
- Measuring range: 0 – 5,000,000 #/cm^3.
- Measuring accuracy +/- 25%.
- Stabilization time (T0 – T95) of the PN-counter (incl. sample line) is less than 15 seconds.
- Measuring frequency of the PN-counter is at least 1 Hz.

For the Netherlands PTI, particle counters approved by NMi will have to be used. In 2019, NMi will set up a procedure for the national certification of particle counters for direct use in the exhaust of a car. This procedure includes the type approval, first inspection, and periodic reinspection of particle counters for stationary cars with idling engine. It is expected that by the end of 2019 NMi will be able to issue national certificates of approval for particle counters. Various manufacturers have indicated that they are working on the development of prototype particle counters for use in car workshops. If these manufacturers pass the certification procedure at NMi, the developed instruments can be placed on the Dutch market as instruments approved by NMi for checking the particulate emission in PTI or RSI tests.

Not only nationally approved instruments by NMi, but particle counters approved by an independent inspection body in another country can also be used, on the condition that the admission requirements are at least on the same level as the national requirements. The Nanoparticle Emission Tester (NPET) Model 3795 from manufacturer TSI has been approved by the Swiss institute METAS according to the Swiss Regulation SR 941.242 (2014) for Non-Road Mobile Tools. The requirements of this regulation are on the same level as the proposed Dutch regulation. Furthermore, the measuring procedure of the TSI NPET fulfils the proposed requirements for the test procedure in the Netherlands. Therefore, DPF checks at RDW test stations and road side Inspections can be done in the Netherlands with the TSI NPET, before NMi certified PTI particulate counters become available on the market.

4. PTI Emission test

The PTI DPF test is carried out by measuring the number of particles for a period of at least 15 seconds, preceded by a period of 15 seconds for stabilization of the measurement signal. The measuring period of at least 15 seconds may be divide into several parts with intermediate non-measuring periods. If the average of the measurement is below the PN limit value, the vehicle passes the test. A well-functioning filter is very effective in the capture of particles. The particle emissions of a diesel car with a properly functioning filter do not exceed 5,000 particles per cubic centimeter.

The DPF test may be done under all conditions of the engine. This is advantageous as, for example, it is not necessary to do a warm-up ride to bring the engine to operating temperature before starting the test. If the vehicle does not pass the test, a new test may be done with the engine at operating temperature. A warm engine emits fewer particles than a cold engine. Another factor that matters here is whether the Exhaust Gas Recirculation (EGR) system is switched on or not. When the EGR system is switched on (EGR valve open), some exhaust gas is passed through the engine, which leads to a higher particle emission. A DPF test may be done with the EGR system turned off (EGR valve closed). This may be done by running the car with idle engine for some time (taxi mode) or via the OBD connector with an engine diagnostic device.

With the approach described above, this results in the following test procedure. The engine of the vehicle is started, the sample line of the PN-tester is placed in the tail pipe and must take a representative sample of the exhaust gas of the running engine at low idle speed. After stabilization of the running PN-counter (15 seconds), the PN emission of the vehicle is determined over a measuring time of 15 seconds (measuring frequency is 1 Hz). If the PN emission is below the PTI PN limit value, the test passed. If the PN emission is above the limit value, the test failed. The test may be done with a warmed up engine and the EGR valve closed. Appendix 2 contains a schematic overview of the PTI-DPF test procedure.

The procedure only applies to diesel cars and is not meant for petrol cars. The necessity for vehicle conditioning with regard to engine temperature and EGR status is illustrated with an example in Annex 1.

Furthermore, the following conditions must be taken into account:

1. The condition of the DPF must allow a full use of the vehicle over its vehicle speed range.
2. Prior to the PTI emission test, a zero check of the PN-counter should be executed with an HEPA filter on the sample line. The PN-concentration must be less than 5,000 $\#/cm^3$. Per day, only one zero emission check needs to be done with a PN-counter.

5. Limit values

The limit value for the particle emissions in the exhaust gas of a diesel car with a particulate filter is 1,000,000 particles per cubic centimeter for cars up to and including 2014, and 250,000 particles per cubic centimeter for cars as of 2015. At low idle speed, diesel cars without DPF emit approximately 5,000,000 particles per cubic centimeter.

The limit value of 1,000,000 particles per cubic centimeter for cars up to and including 2014 is therefore roughly equivalent to allowing, at most, about 20% of the particles to pass through. The limit value of 250,000 particles per cubic centimeter for cars from 2015 means that, at most, about 5% of the particles are allowed through. Table 1 shows the proposed PTI PN limit values for diesel cars with a filter fitted by the manufacturer.

Table 1: Proposed PTI PN limit values for diesel cars with a factory fitted DPF.

Fuel	Date of first registration	Euro class	Proposed limit value [#/cm^3]
Diesel	< 1-1-2015	Euro 3, 4, 5a, 5b, Euro-VI	1,000,000
Diesel	>= 1-1-2015	Euro 5b, Euro 6 Euro-VI	250,000

Diesel cars with a factory fitted wall flow DPF are defined on basis of the particulate emissions as determined during the European type approval test. In case of passenger cars and delivery vans that have been type approved according to the light duty regime whereby an emissions test is carried out on a chassis dynamometer, a diesel car with a factory fitted DPF means a diesel vehicle with a particle emission smaller or equal to 0.005 gram per kilometer. In case of trucks and busses that have been approved in accordance with the heavy-duty regime, where an engine test is carried out on the test stand, a diesel car with factory fitted DPF means a vehicle with approval in accordance with Euro VI. The DPF test is not meant for diesel cars with a half open retrofit filter.

The cut-off date 1 January 2015 follows from the date at which the Euro 5b standard for particle numbers of 6 x 10^{11} particles per kilometer for passenger cars and delivery vans entered into force – 1 January 2013. Considering the sale of end-of-series Euro-5a vehicles for a period of two years after 1 January 2013, and to keep the administrative procedures simple, the sharper limit value of 250,000 particles per cubic centimeter applies to all diesel cars with a DPF fitted by the manufacturer that were registered from 1 January 2015.

The requirement of 250,000 particles per cubic centimeter at idling speed is in line with the European type approval and sustainability standard for the number of particles emitted by passenger cars and delivery vans from Euro 5b, and for lorries and buses from Euro VI. Studies by TNO and the JRC show that the requirement of 250,000 particles per cubic centimeter is three to five times less stringent than the Euro-5b standard for particle emissions of 6 x 10^{11} particles per kilometer.

Figure 1 shows the correlation between idle solid particulate number (SPN 23) emission measured by prototype particulate counters and SPN PEMS compliant instruments (Limit value 6×10^{11} #/km). The JRC study summarized the results from three different studies, Figure 1: (1) TNO study at low idle with three vehicles; (2) JRC NPTI instruments pre-evaluation with one DPF equipped vehicle with bypass at low idle; and (3) SPN-PEMS evaluation study using idle data of the NEDC and WLTC.

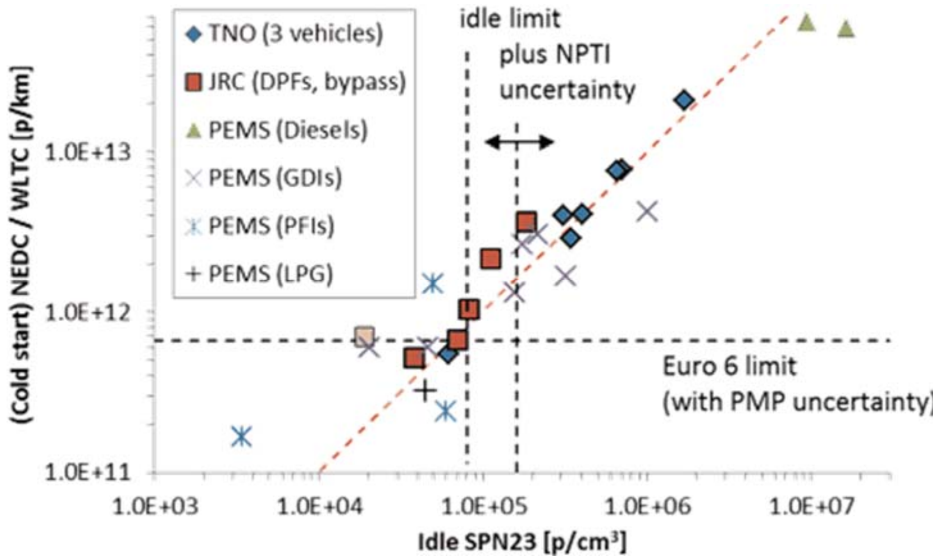


Figure 1: Emission factor (#/km) during NEDC or WLTC vs raw exhaust concentration (#/cm³) measured during low idle with different PMP or SPN-PEMS instruments (Source: JRC)

6. Miscellaneous

- Test procedure saves time and costs:
  The test procedure allows to do the test under all test conditions. The advantage of this is that the test can be carried out quickly, as no warm-up ride must be done and a no waiting time is required to let the vehicle go into taxi-mode. However, the PTI PN measurements may also be executed with a warm engine and inactive EGR system. These conditions are more favorable than a cold engine and active EGR. A good working DPF has a very high filtration efficiency. With a good filter the test is also passed under less favorable conditions.
- Test with EGR system switched off:
  The proposed DPF test may be done with the EGR system switched off. Under these vehicle conditions lower engine-out PN emissions occur than with the EGR system turned on. The advantage of a DPF test with the EGR system switched off is that the proper functioning of the EGR system does not play a role in fulfilling the test. Older diesel cars with DPF problems may also have EGR problems. In case of a test with the EGR switched off, diesel cars with a manipulated EGR system do not have an improper advantage over diesel cars with a properly working EGR system. This improper advantage may occur in a DPF test with the EGR system switched on.
- During a DPF regeneration the proposed DPF test cannot be executed.
- DPF soot load:
  It is recommended that the PTI emission test is performed with a DPF load of more than 10%, because then the filtration efficiency of the DPF is relatively stable and high. The filtration efficiency of the DPF is somewhat decreased just after a full DPF regeneration. The functioning of a DPF can therefore be poorer just after DPF regeneration. DPF load will not be explicitly part of the test procedure. A 10% soot load is built up during a drive of, for example, 50 km. So another DPF test could be done after a test drive of 50 km to get a higher soot load, in case a car narrowly failed the first test.

List of abbreviations

DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
GPF	Gasoline Particulate Filter
HD	Heavy Duty
HEPA	High Efficiency Particulate Air
JRC	Joint Research Centre
LCV	Light Commercial Vehicles
LD	Light Duty
NEDC	New European Driving Cycle
NMi	Nederlands Meetinstituut (Dutch Metrological Institute)
NPTI	New Periodic Technical Inspection
OBD	On Board Diagnostics
OIML	International Organization for Legal Metrology
PEMS	Portable Emission Measurement System
PMP	Particle Measurement Program
PN	Particulate Number
PTB	Physikalisch-Technische Bundesanstalt
PTI	Periodic Technical Inspection
RDE	Real Driving Emissions
RDW	Rijksdienst voor Wegverkeer (Dutch Type Approval Authority)
SPN	Solid Particle Number
RSI	Road Side Inspection
TNO	Netherlands Organisation for Applied Research
VPR	Volatile Particle Remover
WLTC	Worldwide harmonized light vehicles test procedure

Appendix 1. Necessity for vehicle conditioning

A good working DPF can reduce PN emissions considerably. A well-functioning filter allows around one in a thousand particles to pass through.

So, if low idle engine-out emission of a car is 5,000,000 particulates per cm^3, the PN concentration after the DPF will be around 5,000,000 / 1,000 = 5,000 particulates per cm^3.

However, if the efficiency of the filter is poorer, a clear decision must be made as to whether a car passes the test or not. For this, the conditioning of the vehicle with regard to engine temperature and EGR status (EGR valve closed) matters. This is illustrated with the following example.

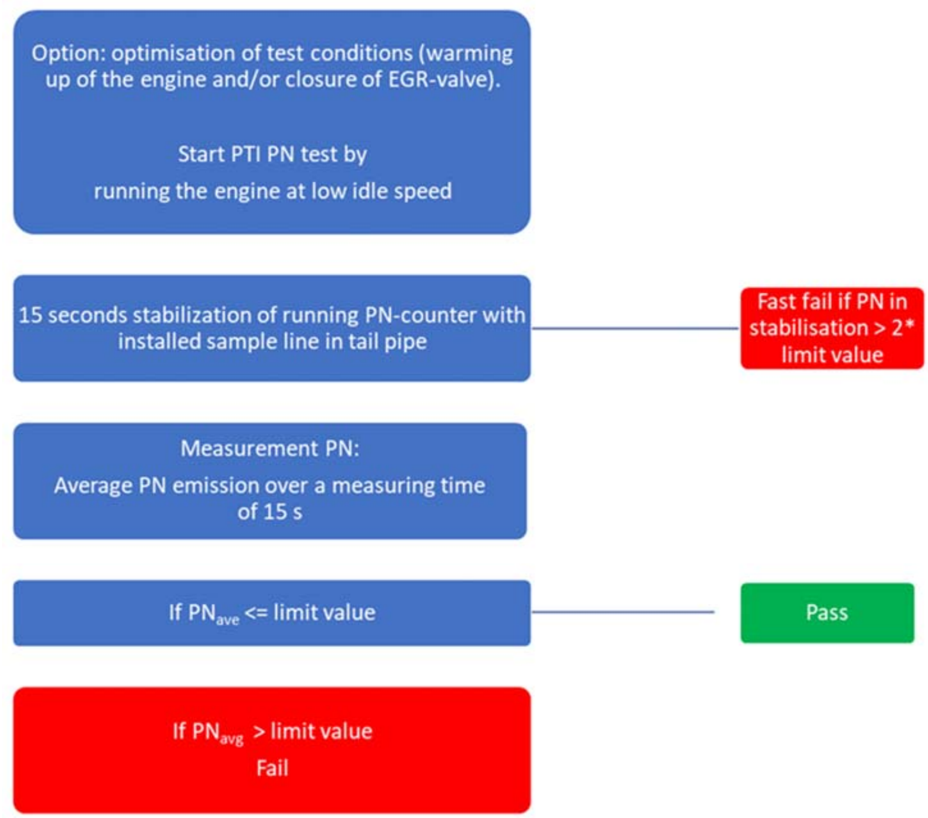
A car has a low idle engine-out emission of 15,000,000 particulates per cm^3 with a cold engine and EGR valve open, and with a warm engine and EGR valve closed, the engine-out PN emission is 5,000,000 particulates per cm^3. Furthermore, the car's filter has a little crack, so that 10% of the particulates passes through the filter. Finally, the vehicle was registered before 2015, so that the PN limit value for PTI is 1,000,000 particulates per cm^3.

With a cold engine and EGR valve open (EGR working), the PN concentration after DPF will be 15,000,000 / 10 = 1,500,000 particulates per cm^3. So, the car will not pass the first test. With a warm engine and EGR valve close (EGR not working, taxi-mode), the PN concentration after DPF will be 5,000,000 / 10 = 500,000 particulates per cm^3. So, the car will pass the second test. Usually, the filter will work well in most cases (> 90%). So, also with a cold engine and unknown EGR-status a car will pass the test. However, in case of a DPF with a small crack, the engine temperature and EGR-status will also determine whether a car passes the test or not.

If a car does not pass a test (less than 10% of cases), a new test may be done with warm engine and the engine running idling for some time, so that the vehicle is given the opportunity to go into taxi-mode (EGR valve closed). With only a small crack in the filter, the car will pass the new test. However, with a removed or completely damaged filter, the car will also not pass the new test.

The possibility to do a new test with a warm engine and in taxi-mode is of particular interest when doing PTI tests at service shops. In the Netherlands in a lot of cases DPF controls for PTI will be done with a cold engine. With the proposed procedure, PTI inspectors do not have to perform a warming-up ride and wait some minutes before they can do the PTI check of the DPF with a particulate counter. Only when a car does not pass the test (less than 10% of the cases), they would have to do a new test after having done a warming up ride and waiting some minutes or close the EGR valve actively with an OBD tester.

Appendix 2. Overview PTI-PN-DPF test procedure.



H Field investigation data

In 2019 the Dutch RDW performed field investigations with 126 passenger, 83 light commercial and 28 heavy-duty vehicles. The PN emission at low idle speed was measured with different prototype PN testers.

In Table H-1 an overview of the failure rates is given (based on the Dutch PTI PN limit values). The results are sorted per vehicle category and Euro class as well as in failure classes. For Euro 4, 5a and EEV vehicles the applied PN limit value is 1,000,000 #/cm^3 and for Euro 5b and 6 vehicles 250,000 #/cm^3. All failed vehicles were further classified as light failure (PN < 3,000,000 #/cm^3) or heavy failure/removal (PN > 3,000,000 #/cm^3).

Table H-1: Overview of results of field investigations with PN measurements at low idle speed

Vehicle class	Euro class	Total	Pass	Fail	Light failure PN<3E06	Removal or Heavy failure PN>3E06		Fail%	Light Fail%	Heavy Fail%
M	4	7	3	4	1	3		57.1%	14.3%	42.9%
	5a*	62	50	12	7	5		19.4%	11.3%	8.1%
	5b**	10	10	0	0	0		0.0%	0.0%	0.0%
	6	47	45	2	2	0		4.3%	4.3%	0.0%
	Total	126	108	18	10	8		14.3%	7.9%	6.3%
N1	4	3	3	0	0	0		0.0%	0.0%	0.0%
	5a*	28	25	3	1	2		10.7%	3.6%	7.1%
	5b**	17	14	3	2	1		17.6%	11.8%	5.9%
	EEV	4	3	1	0	1		25.0%	0.0%	25.0%
	6	31	29	2	1	1		6.5%	3.2%	3.2%
	Total	83	74	9	4	5		10.8%	4.8%	6.0%
N3	III	1	1	0	0	0		0.0%	0.0%	0.0%
	VI	26	25	1	1	0		3.8%	3.8%	0.0%
	Total	27	26	1	1	0		3.7%	3.7%	0.0%

* Euro 5a is defined as Euro 5a and Euro 5b vehicles with date of first registration before 01-01-2015.

** Euro 5b is defined as Euro 5b vehicles with date of first registration from 01-01-2015.

More detailed results are reported in the next tables.

M-category vehicles

Euro-nor	Date 1e registratic	Engine ter	Mileag	PN value	DPF	Pass	Fail
4	22-10-04	warm	314144	800	y	1	0
4	3-01-06	warm	261010	9610000	y	0	1
4	23-04-07	warm	236213	8326947	y	0	1
4	10-05-07	warm	522261	6240000	y	0	1
4	28-02-09	warm	203479	87000	y	1	0
4	11-08-09	warm	262625	272	y	1	0
4	13-04-10	warm	150170	1797000	y	0	1
5	13-08-09	warm	270578	2800000	y	0	1
5	10-09-09	warm	210000	1320000	y	0	1
5	25-06-10	warm	330775	209700	y	1	0
5	22-07-10	warm	837486	10800000	y	0	1
5	17-08-10	warm	140000	130000	y	1	0
5	14-01-11	cold	140000	210000	y	1	0
5	28-01-11	warm	272300	6700	y	1	0
5	31-1-2011	cold	195000	3100000	y	0	1
5	11-02-11	warm	27200	100	y	1	0
5	14-02-11	warm	220000	1400	y	1	0
5	28-02-11	warm	200121	750	y	1	0
5	16-03-11	warm	237500	100	y	1	0
5	24-03-11	warm	116358	18000	y	1	0
5	4-04-11	warm	201800	360000	y	1	0
5	22-04-11	warm	170000	1230000	y	0	1
5	16-6-2011	warm	192931	136000	y	1	0
5	15-08-11	warm	217000	1500000	y	0	1
5	28-11-11	warm	196000	10	y	1	0
5	26-12-2011	warm	232284	4400000	y	0	1
5	6-01-12	warm	544201	1600000	y	0	1
5	10-04-12	warm	230000	2500	y	1	0
5	25-04-12	warm	159000	60000	y	1	0
5	14-05-12	warm	228892	2400	y	1	0
5	29-5-2012	warm	119189	1115000	y	0	1
5	1-06-12	warm	202000	540000	y	1	0
5	3-08-12	warm	123000	23000	y	1	0
5	28-09-12	warm	125000	150000	y	1	0
5	29-10-12	warm	178633	3800	y	1	0
5	17-12-12	warm	188000	2000	y	1	0
5	12-01-13	warm	181000	500	y	1	0
5	1-3-2013	warm	96886	8520	y	1	0
5	15-3-2013	warm	97928	4350	y	1	0
5	26-04-13	warm	186000	800	y	1	0
5	1-7-2013	warm	94563	371000	y	1	0
5	29-7-2013	warm	115,975	1890	y	1	0

5	5-8-2013	warm	106303	6780	y	1	0
5	23-8-2013	warm	92525	3380000	y	0	1
5	30-08-13	warm	132000	1670000	y	0	1
5	5-09-13	warm	137124	25000	y	1	0
5	27-11-13	warm	95138	15	y	1	0
5	27-12-2013	warm	196,820	348000	y	1	0
5	30-12-13	warm	170000	2000	y	1	0
5	9-1-2014	warm	69,047	12600	y	1	0
5	20-01-14	warm	106000	300000	y	1	0
5	30-01-14	warm	220228	160	y	1	0
5	5-3-2014	warm	123,864	678	y	1	0
5	31-03-14	warm	-	200	y	1	0
5	25-4-2014	warm	117,388	4050	y	1	0
5	6-05-14	warm	189263	7400	y	1	0
5	22-5-2014	cold	190078	7140	y	1	0
5	23-5-2014	cold	157171	1440	y	1	0
5	16-06-14	warm	280000	12000	y	1	0
5	16-6-2014	warm	92,447	15500	y	1	0
5	18-6-2014	warm	95280	8	y	1	0
5	25-06-14	warm	282236	7880000	y	0	1
5	26-06-14	warm	236325	10	y	1	0
5	30-6-2014	warm	52,344	0	y	1	0
5	10-7-2014	warm	26406	34	y	1	0
5	26-8-2014	warm	174433	11	y	1	0
5	19-9-2014	warm	112966	9570	y	1	0
5	16-12-2014	cold	190942	650	y	1	0
5	17-12-14	warm	371796	74	y	1	0
5	22-1-2015	warm	90948	1930	y	1	0
5	6-02-15	warm	79212	62000	y	1	0
5	17-02-15	warm	180000	9	y	1	0
5	11-3-2015	warm	74252	3000	y	1	0
5	15-05-15	cold	88187	200	y	1	0
5	27-5-2015	warm	68086	370	y	1	0
5	28-08-15	warm	89000	0	y	1	0
5	23-11-15	warm	65900	8000	y	1	0
5	9-8-2016	warm	19703	3	y	1	0
5		warm	134714	8090	y	1	0
6	5-11-13	warm	186000	8100	y	1	0
6	19-06-14	warm	899425	50	y	1	0
6	3-01-15	warm	391861	15000	y	1	0
6	27-3-2015	cold	162000	20	y	1	0
6	10-9-2015	warm	60212	60500	y	1	0
6	13-10-15	warm	113000	50	y	1	0

6	26-11-2015	warm	155574	450	y	1	0
6	30-11-2015	warm	53,881	4	y	1	0
6	18-12-15	warm	124059	2900	y	1	0
6	24-12-2015	cold	100408	9800	y	1	0
6	29-12-2015	cold	138245	1530000	y	0	1
6	13-1-2016	warm	97515	15700	y	1	0
6	18-01-16	cold	54310	1300	y	1	0
6	22-1-2016	warm	137000	150	y	1	0
6	10-2-2016	warm	81341	14624	y	1	0
6	12-2-2016	cold	130,266	10300	y	1	0
6	17-3-2016	warm	91539	12000	y	1	0
6	9-06-16	warm	115600	175000	y	1	0
6	22-06-16	warm	123688	200	y	1	0
6	15-7-2016	cold	27150	2200	y	1	0
6	22-7-2016	warm	52418	3000	y	1	0
6	31-08-16	warm	94000	9	y	1	0
6	23-09-16	warm	72000	20	y	1	0
6	23-9-2016	warm	51014	1000	y	1	0
6	26-09-16	warm	40000	4300	y	1	0
6	25-10-2016	warm	64564	0	y	1	0
6	12-11-16	warm	195000	300	y	1	0
6	20-01-17	warm	59744	21000	y	1	0
6	2-2-2017	warm	28578	17414	y	1	0
6	13-3-2017	warm	64033	769	y	1	0
6	4-04-17	warm	52000	30	y	1	0
6	2-06-17	warm	44809	0	y	1	0
6	16-10-17	warm	136100	440000	y	0	1
6	31-10-17	warm	67000	1500	y	1	0
6	9-11-2017	warm	12456	18	y	1	0
6	19-12-17	cold	43537	1000	y	1	0
6	12-01-18	cold	16827	39900	y	1	0
6	22-2-2018	cold	45587	0	y	1	0
6	28-03-18	warm	70640	300	y	1	0
6	29-3-2018	warm	26058	52	y	1	0
6	30-03-18	warm	51847	9	y	1	0
6	30-5-2018	warm	25748	0	y	1	0
6	1-08-18	warm	45396	500	y	1	0
6	15-10-18	warm	34191	800	y	1	0
6	15-01-19	warm	17830	9000	y	1	0
6	11-04-19	warm	187250	300	y	1	0
6	25-04-19	warm	89114	800	y	1	0
						108	18
						85.7%	14.3%

N1-category vehicles

Euro-nor	Date 1e registratic	Engine ter	Mileag	PN value	DPF	Pass	Fail
4	26-08-08	warm	131051	30000	y	1	0
4	17-02-10	cold	352825	19400	y	1	0
4	28-04-11	warm	226000	1570	y	1	0
5	2-10-09	warm	416000	25000	y	1	0
5	3-02-11	warm	210000	1200	y	1	0
5	9-02-11	warm	226557	48000	y	1	0
5	21-06-11	warm	227615	12000	y	1	0
5	1-8-2011	cold	155586	449000	y	1	0
5	2-09-11	warm	211000	490000	y	1	0
5	9-01-12	warm	74860	0	y	1	0
5	7-03-12	warm	262291	8000	y	1	0
5	15-05-12	warm	241500	13	y	1	0
5	1-06-12	warm	224115	4000000	y	0	1
5	18-10-12	warm	227610	13000	y	1	0
5	30-11-12	warm	264187	34500	y	1	0
5	30-01-13	warm	168000	4000000	y	0	1
5	18-2-2013	warm	229364	2000	y	1	0
5	27-02-13	warm	235770	200	y	1	0
5	23-03-13	warm	280676	18500	y	1	0
5	5-9-2013	warm	171917	3000	y	1	0
5	20-09-13	warm	304271	2050000	y	0	1
5	25-09-13	warm	209302	3075	y	1	0
5	27-09-13	warm	165902	3500	y	1	0
5	10-10-13	warm	172213	220000	y	1	0
5	13-11-13	warm	177383	525000	y	1	0
5	19-11-13	warm	17601	17	y	1	0
5	6-01-14	warm	73680	24000	y	1	0
5	5-3-2014	warm	197000	0	y	1	0
5	1-04-14	warm	180213	100	y	1	0
5	17-4-2014	warm	92011	2190	y	1	0
5	3-07-14	warm	101513	95000	y	1	0
5	30-3-2015	warm	74144	3000	y	1	0
5	31-03-15	warm	286069	12000	y	1	0
5	12-06-15	warm	152000	600	y	1	0
5	14-08-15	warm	14162	30	y	1	0
5	6-11-15	warm	79000	4000	y	1	0
5	16-11-15	warm	125595	3200000	y	0	1
5	1-02-16	warm	90000	0	y	1	0
5	11-3-2016	warm	60731	2800	y	1	0
5	14-05-16	warm	87616	20	y	1	0
5	17-05-16	warm	115237	1650000	y	0	1

5	14-6-2016	warm	110497	0	y	1	0
5	27-06-16	warm	102338	6500	y	1	0
5	13-07-16	warm	114937	10	y	1	0
5	22-08-16	warm	87000	500	y	1	0
5	31-08-16	warm	188000	775	y	1	0
5	26-01-17	cold	14600	275000	y	0	1
5	23-03-17	warm	55532	100	y	1	0
6	2019		13	0	y	1	0
6	12-06-15	warm	100000	26	y	1	0
6	4-04-16	warm	38647	20670	y	1	0
6	21-06-16	warm	480296	9250000	y	0	1
6	23-06-16	warm	92000	20	y	1	0
6	25-1-2017	warm	7862	9	y	1	0
6	22-03-17	warm	29830	200	y	1	0
6	18-05-17	warm	36882	760000	y	0	1
6	23-05-17	warm	190000	800	y	1	0
6	22-09-17	warm	93688	2000	y	1	0
6	27-09-17	warm	16200	30	y	1	0
6	17-11-17	warm	176000	0	y	1	0
6	29-11-17	warm	26000	120	y	1	0
6	21-02-18	warm	71493	51	y	1	0
6	28-02-18	cold	1529	22	y	1	0
6	28-03-18	warm	55000	5000	y	1	0
6	18-06-18	warm	10197	86	y	1	0
6	22-06-18	warm	15000	90	y	1	0
6	11-7-2018	warm	50	6	y	1	0
6	6-08-18	warm	44181	41	y	1	0
6	10-8-2018	warm	21016	3000	y	1	0
6	16-10-2018	warm	25	0	y	1	0
6	7-11-18	warm	20000	9	y	1	0
6	29-11-18	warm	10875	4000	y	1	0
6	29-01-19	warm	15945	700	y	1	0
6	8-02-19	warm	15000	0	y	1	0
6	22-02-19	warm	11998	5555	y	1	0
6	1-05-19	warm	1400	600	y	1	0
6	26-6-2019	warm	341	1000	y	1	0
6	23-7-2019	warm	39	0	y	1	0
6	27-07-19	warm	18531	62	y	1	0
eev	8-02-12	warm	238762	176000	y	1	0
eev	3-05-12	warm	126999	228000	y	1	0
eev	22-05-12	warm	333902	50	y	1	0
eev	7-3-2013	warm	149,483	5000000	y	0	1
						74	9
						89.2%	10.8%

N3-category vehicles

Euro-norm	Date 1e registration	Engine temp	Mileage	PN value
VI	27-7-2018	warm	15,575	0
VI	9-5-2019	cold	142000	25
VI	16-10-2013	warm	205,936	40
VI	8-6-2018	cold	137570	120
VI	24-5-2019	cold	290	500
VI	5-12-2014	warm	486,685	1000
VI	10-6-2014	warm	528122	1000
VI	19-12-2013	cold	722702	1200
VI	12-10-2015	cold	168510	2000
VI	13-10-2016	warm	318005	2200
VI	6-8-2019	cold	1200	2500
VI		warm	336,038	2730
VI	6-4-2017	warm	100,687	2800
VI	1-5-2014	warm	663499	3200
VI	1-11-2016	warm	149000	4000
VI	8-2-2018	cold	154230	4300
VI	15-1-2018	cold	25000	5000
VI		warm	452,928	7760
III	12-7-2005	warm	797528	8000
VI		warm	96,583	8070
VI	23-2-2017	warm	314,744	10000
VI	24-8-2018	cold	96423	13000
VI		warm	135,416	86900
VI	16-6-2015	cold	503900	120000
VI	17-8-2018	warm	66000	228000
VI	1-09-17	cold	277000	330000
VI	6-8-2015	cold	712418	1500000