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TNO report

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Emissions of three common GDI vehicles

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Samenvatting

De laatste jaren is het aandeel benzinevoertuigen met directe injectie (Gasoline Direct Injection, ofwel GDI) sterk toegenomen. In 2015 betrof dit in Nederland bijna de helft van de verkoop van alle nieuwe benzineauto's. Het is daarom belangrijk om vast te stellen of deze voertuigen vergelijkbare emissies hebben als andere benzineauto's, of dat deze groep bijzondere aandacht behoeft in de emissieregistratie en luchtkwaliteitsmodellen. In het bijzonder kunnen de emissies van deeltjesaantallen, fijnstofmassa (PM10) en elementair koolstof afwijken van andere benzineauto's ten gevolge van de specifieke GDI technologie.

Van de vijf meest verkochte GDI voertuigmodellen van de laatste jaren zijn er drie geselecteerd van verschillende fabrikanten. Deze drie voertuigen zijn op de rollenbank in het laboratorium bij een temperatuur van 23-25 °C onderworpen aan testen op een voor de praktijk representatieve ritcyclus. De instellingen en de testen komen overeen met een belading en rijweerstand die aan de hoge kant liggen van normaal gebruik. Dit is gedaan om er voor te zorgen dat de emissies niet onderschat worden met deze testen. Desondanks presteerden alle voertuigen goed, met emissies die vergelijkbaar zijn met de emissielimieten op de typekeuringstest.

De fractie van het elementair koolstof in de fijnstof-emissies is hoger dan voor andere benzinevoertuigen. Maar de absolute fijnstof-emissies in milligrammen per kilometer zijn dusdanig laag dat de uitstoot van elementair koolstof door deze GDI's niet substantieel bijdraagt aan de fijnstof-concentraties in de lucht. Ook is de uitstoot van de andere schadelijke emissies laag en vergelijkbaar met de uitstoot van andere moderne benzinevoertuigen.

Vanaf Euro-6 moeten GDI's voldoen aan een deeltjesaantallen-eis van 6×10^{12} deeltjes per kilometer in de typekeuring. Deze eis is minder streng dan voor vergelijkbare dieselvoertuigen. De deeltjesaantallen-emissies van GDI's in de praktijktesten zijn inderdaad hoger dan van dieselvoertuigen met een gesloten roetfilter, maar de gemeten waarden zijn consistent met de eisen die aan deze voertuigen gesteld worden. De GDI's vertonen in de praktijk geen afwijkend gedrag ten opzichte van de typekeuringstest op de rollenbank. Vanaf 1 september 2017 moeten nieuwe GDI modellen aan de strengere eis voor deeltjesaantallen van 6×10^{11} deeltjes per kilometer voldoen. Naar verwachting zullen de praktijkemissies van deze voertuigen daarmee nog verder verbeteren.

Summary

The share of petrol passenger cars with Gasoline Direct Injection (GDI) technology quickly increases in the total sales of new petrol passenger cars. In The Netherlands almost half of the total sales of petrol vehicles in 2015 are GDI's. Therefore, it is important to establish the emissions of these vehicles and to investigate whether a distinction as a special vehicle category in the emission inventories and air quality models would be appropriate. Special attention is given to the emissions of particulate mass and particulate numbers, and the elemental carbon fraction in the particulate mass. On these pollutants GDI technology is expected to deviate the most from other petrol cars.

Three vehicles with common GDI engines from different manufacturers in the top five of GDI sales of the last years have been selected. The vehicles have been tested in a laboratory on a chassis dynamometer with a test cell temperature of 23-25 °C with a real-world test cycle and normal to high engine loads, to ensure that the effects of real-world emissions are not underestimated. Still, all the vehicles perform well. The emission results in the real-world tests are more or less consistent with the vehicles' performance on the type-approval test.

The fraction of elemental carbon (EC) in the PM10 emissions of GDI vehicles is higher than for other petrol vehicles. Given the low absolute PM10 emission levels there is no specific concern regarding EC emissions of GDI's, nor regarding the other pollutant emissions considered.

The current particulate number emission limit for Euro-6 GDI's is less strict than for diesel vehicles. The tests indicate that GDI vehicles perform worse on particulate numbers than their diesel counterparts. However, the particulate number emissions in real-world tests are generally consistent with the type-approval limits. The type-approval PN emission limit for GDI will become more stringent from 1 September 2017 onwards. The current limit value of 6×10^{12} particulates per kilometre will reduce to 6×10^{11} particulates per kilometre. The real-world emissions are expected to decrease accordingly.

Contents

1 Introduction

Particulates from the vehicle exhaust are known to cause health problems. Therefore, particulate matter emissions are regulated for relevant vehicles, which can emit substantial amounts of particulate matter. For a long time this concerned only diesel vehicles, but with the introduction of modern direct fuel injection technology (GDI: Gasoline Direct Injection) also petrol vehicles are reported to emit particulate matter. These emerging group of petrol vehicles are the subject of the study reported here. The study concerns the performance of such vehicles under real-world driving conditions, not the legal results under type-approval test conditions., and aims to establish the actual contribution of these vehicles to air-quality problems.

However, particulate matter emissions cannot yet be tested on-road. At the moment no official mobile PEMS equipment is available to measure these emissions. Therefore, the tests are performed in the laboratory mimicking real-world conditions under which particulate emissions may be substantial, such as high velocities and high vehicle loads[1]. In the future, accurate PEMS-PN equipment should enable on-road testing and enable the assessment of the real-world performance of such vehicles within the limits.

Direct fuel injection technology with petrol passenger cars was for a long time applied only in a small fraction of the petrol passenger cars sold in the Netherlands. Recently, petrol direct injection technology has become more common. Soon more than half of the petrol vehicles sold will have direct injection. Given the fact that these vehicles also emit particulate matter (PM) they are of some concern for air quality and will be considered as a separate vehicle category in emission inventories.

Table 1 The different emission limits for PM and PN associated with the different Euro-classes for diesel passenger cars and GDI's.

	introduction dates		PM [mg/km]		PN [#/km]	
	new models	all models	diesel	GDI	diesel	GDI
Euro-4	1-Jan-2005	1-Jan-2006	25	-	-	-
Euro-5a	1-Sep-2009	1-Sep-2010	5	5	-	-
Euro-5b	1-Sep-2011	1-Sep-2012	4.5	4.5	6.0E+11	-
Euro-6	1-Sep-2014	1-Sep-2015	4.5	4.5	6.0E+11	6.0E+12
Euro-6c	1-Sep-2017	1-Sep-2018	4.5	4.5	6.0E+11	6.0E+11

As shown in Table 1 with the coming into force of Euro-5 (starting from 2009) the type-approval test for particulate matter was compulsory for GDI’s, with the same emission limit of 5 mg/km as for diesel vehicles. The more strict particulates number emission limit of 6×10^{11} #/km, from Euro-5b (2011) for diesel vehicles, was applied with a lower limit of 6×10^{12} #/km from Euro-6 (2014) for GDI vehicles. In type-approval GDI’s clearly have higher particulate number emissions than diesel vehicles (see figure 1). Moreover, there is some correlation between the particulate number and the particulate mass emissions on the type-approval test. This situation

[1] For more information on TNO test methods for laboratory and on-road testing see: TNO 2016 R11178, “Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme”, V.A.M. Heijne et al., 2016

is meant to be temporary until three years after the initial date of the introduction of Euro-6. With the coming into force of Euro-6c the particulate mass and number emissions of GDI's should satisfy, in all aspects, the same limits and standards as those of diesel vehicles. This also means that RDE legislation should incorporate a particulate number test and set an appropriate limit.

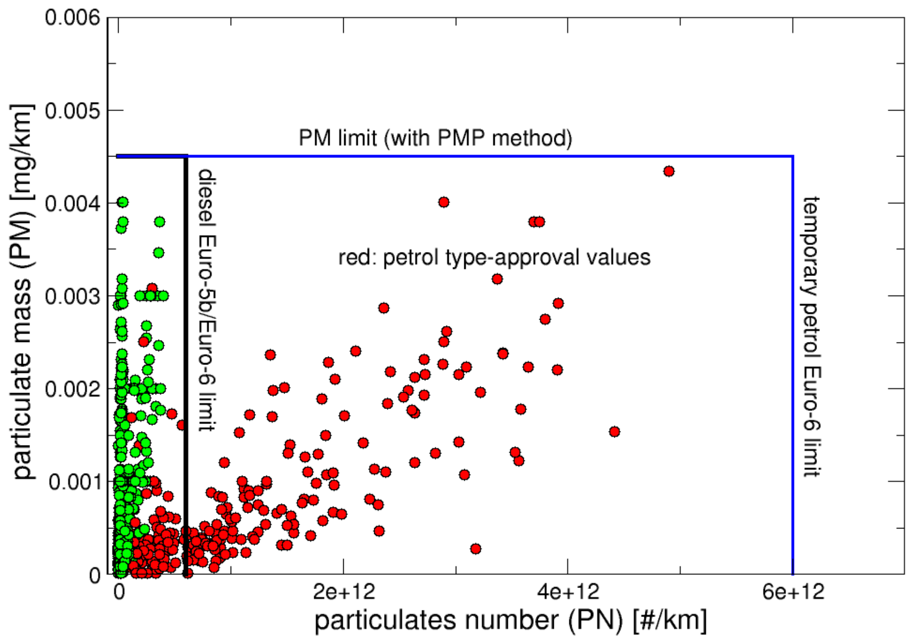

Figure 1 The particulate mass and particulate number measurement results in the NEDC type approval test of diesel vehicle models (green) and GDI's (red) which are sold in the last two years. The particulate number limit of GDI's is 6 10^{12} #/km, while the diesel vehicles have a limit of 6 10^{11} #/km.

The tests reported here were also designed and executed to obtain elemental carbon (EC) emission factors for GDI's. For the GDI vehicles limited information on EC emissions is available. From the technology it is to be expected that the fraction of elemental carbon in the particulate mass is higher than for other petrol vehicles. This test program fills an important gap in the knowledge underlying the EC emission factors used in the Netherlands.

2 Emergence of GDI’s

In the past GDI’s were a small group among all petrol vehicles sold. With the introduction of European CO_2 targets, GDI technology became a way to increase the efficiency of a petrol engine. Hence in the last few years GDI’s were sold in larger numbers. In 2010 the GDI’s were only 1% of the total petrol vehicle fleet. Currently, summer 2016, the GDI’s form 9% of the total Dutch petrol fleet. In the last two years GDI’s make up 44% of the total sales. In particular, small engines (0.9-1.2 litres) with substantial power of 60–100 kW are sold in large numbers.

Given the current sales of GDI’s rapidly approaching 50%, the replacement of the other, older petrol technology will be at a rate of about 4% a year. Therefore, it is decided to take GDI’s into consideration as a separate vehicle category in the national emission inventories and air quality models for which separate emission factors may be needed.

Given the fact that particulate mass emissions of GDI’s are regulated from early on, the particulates mass emissions of GDI’s may be low. The more lenient intermediate particulate number emission limit of GDI’s from Euro-6 onwards, however, gives concern that GDI technology may not keep pace with the more stringent particle number standards for diesel vehicles.

Particulate matter emissions are not the only concern related to GDI’s, but also the sophisticated engine control, for which more complex and specific optimizations can be used. These optimizations may lead to an increase in NO_x or CO emissions in real-world driving conditions. The most quoted reason to use adapted control strategies for GDI’s is the reduction of real-world fuel consumption. If the engine is operated under partial lean-burn conditions, fuel consumption may decrease, but a deviation from near stoichiometric operation associated with the optimal functioning of the three-way catalyst, might increase NO_x, CO, and HC exhaust gas emissions.

3 Test specification and vehicle selection

3.1 High load chassis dynamometer emission tests

High particulates emissions are associated with high engine load and high fuel consumption. As the test program is set up to assess the risks of high PM and PN emissions, the tests are conducted with engine loads that are at the higher end of the spectrum of normal vehicle use in the Netherlands. This means that the engine loads in the test are higher than what is common for the type-approval tests. This is achieved by setting the driving resistance and test mass on the high side of normal use. The applied values are comparable to carrying two passengers and, for example, the use of C or D-label tyres.

Table 2 The settings of the chassis dynamometer for the test mass and driving resistance.

road-load settings	
mass	1450 kg
F0	130 N
F1	0 N/[km/h]
F2	0.04 N/[km2/h2]

For the cold urban tests the vehicles were soaked at 23 °C. All chassis dynamometer tests are carried out with a test cell temperature of 23 - 25 °C.

Vehicles are tested on the CADC-150 driving cycle[2], which is considered representative of more aggressive driving within the spectrum of normal driving. The variant of the CADC-cycle used has a maximum velocity of 150 km/h. Therefore, all in all the power demand on the vehicles is on the high side, and the emissions may be somewhat higher than can be expected from average driving. The need of this high demand lies in the fact that emissions may increase rapidly with engine demand and therefore average driving does not necessarily result in average emissions.

Table 3 The parameters of the driving cycle.

CADC-150	distance [km]
urban	4.8
rural	17.2
motorway	29.5
total	51.5

Since particulate matter is collected on a filter, the tests have been repeated three times to collect sufficient particulate matter for an accurate filter particulate mass determination and subsequent chemical analyses. Rather than collecting the emissions of a full CADC cycle on a single filter, the urban, rural and motorway part

[2] For more information on TNO test methods for laboratory and on-road testing see: TNO 2016 R11178, “Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme”, V.A.M. Heijne et al., 2016

are collected on separate filters to have representative particulate mass results for each of these traffic situations.

Moreover, cold starts, when the engine itself is at the ambient temperature, may lead to additional particulates emissions. Cold starts occur mainly in urban driving situations. In the tests cold starts are included in the result of the urban test. For two vehicles the cold start was in each of the three repetitions of the urban test. For the third vehicle only a single cold start was used in the three tests. It is a rather cumbersome procedure to ensure a cold start, which was therefore abandoned later in the test program.

The filters were of pure quartz. These filters can be used for elemental carbon determination using the SUNSET[3] method from the EUSAAR. In this method of determination the filters are heated up to 800 °C. Other types of filters cannot withstand such temperatures, and the filter material itself might contaminate the results.

3.2 Vehicle selection

The vehicle were selected from the top five of high sales of GDI engines in vehicles from different manufacturers. In analysing the sales database engines were characterized by engine volume and rated power. The GDI classification was induced from the fact that the petrol engine was type-approved for particulate matter.

The selected vehicles each represent about 4% of current sales of GDI engines. This small fraction is due to the recent introduction of many more GDI engines. The specifications of the selected vehicles are given in Table 4 to Table 6. They are common models with even more common engines for these manufacturers. In the past Volkswagen had the largest share of GDI vehicles in the total fleet. The Volkswagen Golf was selected from that period. But more recent other manufacturers have increased their share.

[3] F. Cavalli et al., *Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protoco*l, Atmos. Meas. Tech. (2010) 3 p.79-89.

Table 4 Vehicle specifications of the Ford Focus

Trade Mark	[-]	Ford
Type	[-]	Focus
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	Petrol
Engine Code	[-]	
Swept Volume	[cm^3]	999
Max. Power	[kW]	74
Euro Class	[-]	Euro 6
Vehicle Empty Mass	[kg]	1176
Vehicle Test Mass	[kg]	1450
Odometer	[km]	11628
Registration Date	[dd-mm-yy]	17-03-15

Table 5 Vehicle specifications of the Peugeot 308

Trade Mark	[-]	Peugeot
Type	[-]	308
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	Petrol
Engine Code	[-]	
Swept Volume	[cm^3]	1199
Max. Power	[kW]	81
Euro Class	[-]	Euro 6
Vehicle Empty Mass	[kg]	1055
Vehicle Test Mass	[kg]	1450
Odometer	[km]	14268
Registration Date	[dd-mm-yy]	11-12-15

Table 6 Vehicle specifications of the Volkswagen Golf

Trade Mark	[-]	Volkswagen
Type	[-]	Golf
Body	[-]	Station wagon
Vehicle Category	[-]	M
Fuel	[-]	Petrol
Engine Code	[-]	CJZA
Swept Volume	[cm^3]	1197
Max. Power	[kW]	77
Euro Class	[-]	Euro 5
Vehicle Empty Mass	[kg]	1135
Vehicle Test Mass	[kg]	1450
Odometer	[km]	32331
Registration Date	[dd-mm-yy]	03-12-14

4 Emission test results

In Table 7 the results of the three tested vehicles are reported: the urban, rural and motorway parts are listed separately. The emission tests give results for all the regulated pollutants, which are generally in line with the vehicle performance of the vehicles on the type-approval test. Moreover, the test results show no peculiar or systematic deviations.

Table 7 The measurement results of the emission tests of the three vehicles with GDI.

Ford Focus	HC	CO	CO2	NOx	NMHC	CH4	PN	FC	PM (sum)	
	mg/km	mg/km	g/km	mg/km	mg/km	mg/km	#/km	l/100km	mg/km	urban test
urban	165	931	228.7	116	154	12	5.95E+12	9.974		cold
	114	1178	225.8	112	102	13	8.37E+12	9.860		cold
	108	1076	226.1	132	96	14	8.20E+12	9.865	6.1	cold
average	129	1062	226.9	120	117	13	7.51E+12	10	6.1	
rural	15	220	129.9	76	13	2	1.98E+12	5.632		
	7	192	127.2	54	6	1	1.92E+12	5.514		
	17	348	127.8	69	15	2	1.79E+12	5.551	0.8	
average	13	253	128.3	66	11	2	1.90E+12	6	0.8	
Motorway	10	301	169.0	55	9	1	2.56E+12	7.331		
	21	528	171.6	95	19	3	2.81E+12	7.457		
	14	419	172.1	63	12	2	2.56E+12	7.471	2.4	
average	15	416	170.9	71	13	2	2.64E+12	7	2.4	
Peugeot 308	**HC**	**CO**	**CO2**	**NOx**	**NMHC**	**CH4**	**PN**	**FC**	**PM (sum)**	
	mg/km	mg/km	g/km	mg/km	mg/km	mg/km	#/km	l/100km	mg/km	
urban	75	475	230.9	96	68	7	7.49E+12	10.025		cold
	16	117	219.5	330	12	4	2.18E+12	9.503		warm
	11	40	221.3	406	8	4	2.58E+12	9.572	1.8	warm
average	34	210	223.9	277	29	5	4.08E+12	10	1.8	
rural	3	74	122.4	130	2	1	8.21E+10	5.300		
	4	107	125.2	107	3	1	9.98E+10	5.420		
	4	74	125.0	146	3	1	1.08E+11	5.410	0.1	
average	4	85	124.2	128	3	1	9.67E+10	5	0.1	
Motorway	2	224	165.1	66	2	1	3.02E+11	7.156		
	3	180	164.4	78	2	1	3.22E+11	7.121		
	3	210	164.2	87	2	1	2.89E+11	7.117	0.3	
average	3	205	164.6	77	2	1	3.04E+11	7	0.3	
VW Golf	**HC**	**CO**	**CO2**	**NOx**	**NMHC**	**CH4**	**PN**	**FC**	**PM (sum)**	
	mg/km	mg/km	g/km	mg/km	mg/km	mg/km	#/km	l/100km	mg/km	
urban	55	563	224.7	137	48	8	1.92E+12	9.760		cold
	110	1039	232.1	170	100	11	3.02E+12	10.123		cold
	72	937	239.1	121	64	9	1.26E+12	10.413	0.6	cold
average	79	846	232.0	143	71	9	2.07E+12	10	0.6	
rural	18	77	134.7	98	16	1	9.30E+11	5.834		
	10	65	134.5	83	8	1	7.33E+11	5.820		
	2	45	134.6	76	2	1	5.75E+11	5.825	0.1	
average	10	62	134.6	86	9	1	7.46E+11	6	0.1	
Motorway	14	435	171.3	54	10	4	2.26E+12	7.440		
	16	583	171.2	68	12	4	2.53E+12	7.447		
	17	684	170.5	68	13	5	2.27E+12	7.421	0.9	
average	16	567	171.0	63	12	4	2.35E+12	7	0.9	

In all cases the NO_x emissions exceeded the NEDC emission limits, but taking into account that the tests were performed with high load settings of the chassis dynamometer and a normal though demanding cycle and that the separate urban test had a short distance of only 4.8 km, the measured emissions do not raise special concern. In the case of an NEDC type-approval test the additional emission due to a cold start would have been spread over double the distance, yielding lower g/km results for the urban part of the test.

Table 8 The average test results of the three vehicles, based on equal weighing of vehicles and tests.

averages	HC mg/km	CO mg/km	CO2 g/km	NOx mg/km	NMHC mg/km	CH4 mg/km	PN #/km	FC l/100km	PM (sum) mg/km
urban	80	706	227.6	180	72	9	4.55E+12	9.8993	2.8
rural	9	134	129.0	93	8	1	9.13E+11	5.5895	0.3
Motorway	11	396	168.8	71	9	2	1.77E+12	7.3289	1.2
total	33	412	175.1	115	30	4	2.41E+12	7.6059	1.4

Per three tests one single PM filter result is available, which is the sum result of the three repetitions of the same test, collected on a single filter. The PM values are very low, close to the measurement accuracy, such that this repetition is needed to arrive at a reasonable accuracy of the measured particulate mass.

One notable aspect is the NO_x emission of the Peugeot which are higher in the warm urban tests (330 and 406 mg/km) than in the cold tests (96 mg/km). Looking at the second-by-second emission rate over these tests, the two warm tests show similar incidental occurrences of high emissions (see Figure 2). This indicates a failure of the three-way catalyst control strategy, rather than a systematic deviation. The robustness of the three-way catalyst control seems somewhat limited for this vehicle. The introduction of RDE legislation, with on-road testing may help to reduce such incidents of high emissions.

In general emissions of all vehicles and all pollutants are higher under cold start conditions. In this effect the engine soak temperature plays an important role. The cold start tests were conducted at 23 °C laboratory temperature. At lower temperatures[4] the cold start effect is typically larger. The effect is expected to increase gradually as the engine soak temperature decreases. For example, for pollutants that are reduced by the three-way catalyst, which needs to reach operation temperatures, at 0 °C ambient temperature the additional emissions of the cold start are expected to be two or three times higher than at 23 °C. For PM and PN the temperature sensitivity of the cold start effect is smaller.

All vehicles have higher particulate number emissions than comparable diesel vehicles equipped with a DPF (Diesel Particulates Filter) which have emissions below 6×10^{11} #/km. Especially, the cold start urban tests have high particulate number emissions. The values are of minor concern, given the fact that a Euro-4 diesel vehicle without DPF produces typically 10^{13} to 10^{14} #/km. This is a factor 10 to 100 higher than the particulate number emissions of these GDI's.

[4] The average ambient temperature in The Netherlands is 11 °C.

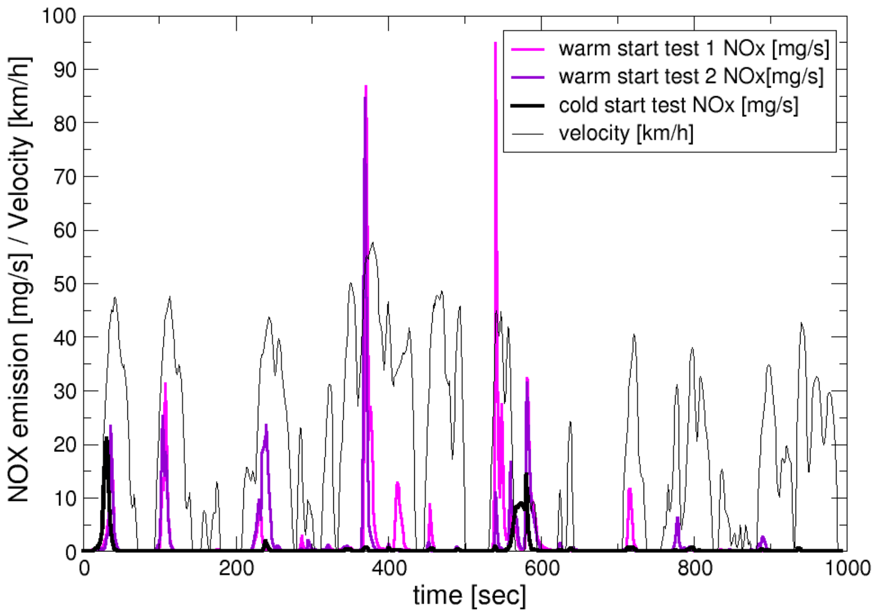

Figure 2 The NO_x emission rates of the Peugeot 308 on the three urban tests show that the higher emissions are incidental, with some correlation between the warm tests.

Also the particulate mass emission is low. Current emission factors for all petrol vehicles are about 5 mg/km. The measured values, despite the demanding tests, are below this current estimate of 5 mg/km. Hence, in terms of absolute emission levels GDI's are of little concern. Moreover, the differences between the vehicles may appear large, but at current levels, below the emission limits, these differences should not be exaggerated. In particular, at these low levels the variation in PM emissions between tests with the same vehicle can be large.

5 Determination of the fraction of elemental carbon

The quartz filters were analysed in a chemical laboratory for the determination of the elemental carbon (EC) fraction compared to the remaining organic carbon fraction. The elemental carbon and the organic carbon together make up the total carbon in PM10 emissions. Generally, there is only a small mass fraction from other elements and the majority of the total mass is carbon. The SUNSET method used is considered to be best suited to determine EC fractions. Other methods, because of their lower end temperatures, may not collect all the carbon from the filters.

Table 9 The fraction of EC, as opposed to the fraction of carbon as part of organic compounds.

Ford Focus		elemental carbon fraction
	urban	82.6%
	rural	33.4%
	motorway	59.8%
Peugeot 308		
	urban	80.6%
	rural	28.0%
	motorway	54.3%
Volkswagen Golf		
	urban	89.5%
	rural	37.7%
	motorway	54.8%

Surprisingly, the fractions of EC in particulate matter are constant across the tested vehicles for a given road type, but vary widely between the road types. The EC fraction is higher than for petrol vehicles without direct injection, which are generally estimated at 30% and less, depending on technology and driving behaviour. It should be noted that organic carbon also contains hydrogen and oxygen, and the total mass fraction of the organic matter is somewhat higher than the mass fraction of carbon alone with about 15% non-carbon components in organic material. In some cases hydrates, metal and ash is collected on the filter, increasing the fraction of carbon-free components. However, since these vehicles are relatively new and in good order, it is not expected that the carbon-free fraction in PM is more than 15%.

Table 10 Typical composition of PM10 emissions of GDI vehicles

	Fraction of PM10	Of which carbon
EC	>60%	100%
Organic matter	<30%	85%
carbon-free fraction	<15%	--

Although the fraction of elemental carbon is substantial, especially for an urban tests with cold start, the absolute levels are very low, ranging from 0.3 to 3 mg/km. Consequently, GDI's have a limited contribution to the total EC emissions of traffic. Only by the time that the large majority of diesel vehicles is equipped with well-functioning diesel particulate filters, the EC emissions of GDI's will become a significant remainder.

6 Conclusions

Given the growing group of vehicles with GDI, specific attention for the emissions of these vehicles is justified. There are suggestions that these vehicles have significantly higher PM emissions in normal use than other petrol vehicles.

In order to gain more insight in PM, PN and EC emissions of GDI vehicles CADC tests were conducted in a chassis dynamometer test programme. To establish the EC fraction, the PM emissions were collected on quartz sample filters, which were analysed in detail later in a chemical laboratory.

For the three tested GDI's, which are common makes and models, the PM10 emissions are in the range of 0.1 to 6.1 mg/km. In general the emissions are consistent with the type approval emission limits of 5.0 mg/km. Deviations can be explained by the more severe test conditions in this test programme, compared to the type-approval test, and multiple inclusion of cold starts.

The ambient air contains particles from many different emission sources, including sand, dust, and sea salt. The particulates from vehicle exhaust are only a small fraction in the total particulate matter. Zooming in on the ambient concentration of specific components of PM10, in particular EC or black carbon, a substantially higher fraction is directly related to tailpipe emissions from vehicles. For most diesel vehicle categories specific EC emissions have been determined in previous test programmes. Based on that the relative contribution of particular vehicle categories to the ambient EC concentration could be established. The intention is that a complete picture for EC emissions of all road vehicles will be available for Dutch air-quality assessments. By adding specific information on EC emissions of GDI's, this study fills an important gap in the current understanding needed for the full assessment.

The particulate number emissions of the three vehicles are in line with the current emission limit value of 6×10^{12} #/km. But unlike the real-world emissions of modern diesel vehicles, the real-world emissions of GDI's are close to the limit value. When the type-approval limit for GDI vehicles will be lowered to 6×10^{11} #/km – as of 1 September 2017 for new models –it is expected that the real-world particulate number emissions will decrease accordingly. Only if particulate filters will be the common technology for GDI's, real-world particulate number emissions might be substantially lower than the limit values, as is already the case for diesel vehicles equipped with particulate filters.

7 Signature

Delft, 6 October 2016

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