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TNO report

TNO 2016 R11123

Review into the relation between ambient temperature and NO_x emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine

Date	4 October 2016
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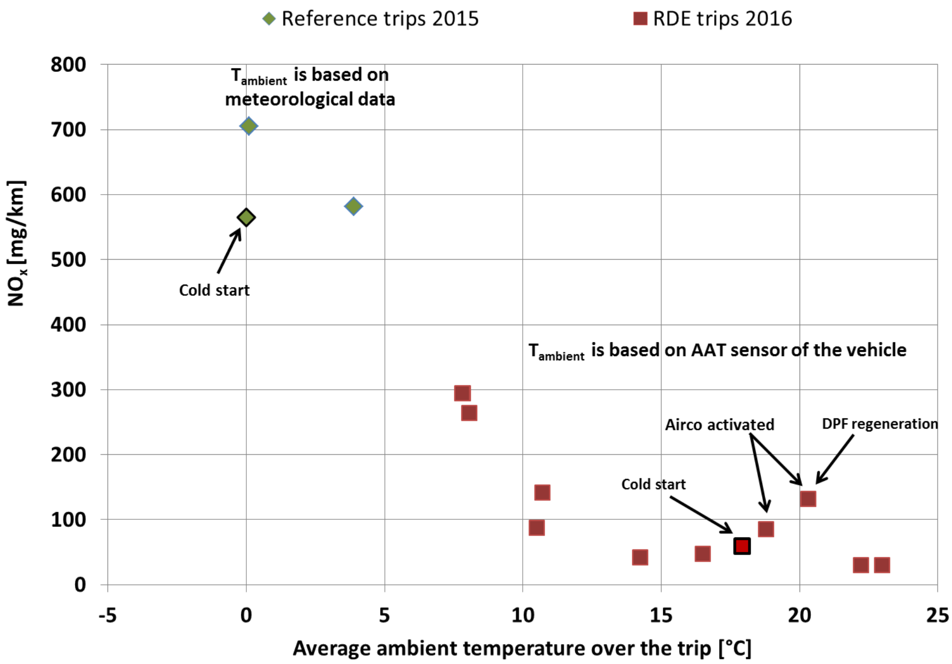
Copy no	2016-TL-RAP-0100299329
Number of pages	17 (incl. appendices)
Number of appendices	1
Sponsor	Dutch Ministry of Infrastructure and the Environment PO Box 20901 2500 EX THE HAGUE The Netherlands
Project name	LD In-use Compliance project 2012-2016
Project number	060.14432

Samenvatting

Dit rapport is een verslag van testresultaten van emissiemetingen op de weg van twee Mercedes C220 Bluetec Euro 6 dieselvoertuigen bij verschillende omgevingstemperaturen. De testresultaten zijn een voorbeeld van hoe voertuigemissies afhankelijk kunnen zijn van de omgevingstemperatuur. De resultaten zijn alleen geldig voor dit specifieke model en zijn niet van toepassing op andere voertuigen. Andere voertuigen kunnen een geheel ander emissiegedrag hebben.

Twee Mercedes C220 Bluetec Euro 6 dieselvoertuigen met identieke technologie zijn op de weg getest. In Figuur NS1 zijn de NO_x-emissies van de twee voertuigen weergegeven als functie van de buitenluchttemperatuur. Als de buitenlucht-temperatuur daalt van 15 °C naar 5 °C nemen de NO_x-praktijkemissies gemiddeld met een factor zeven toe.



Figuur NS1 Gemiddelde NO_x-emissies van twee Mercedes C220 Euro 6 dieselvoertuigen in een referentierit of RDE-rit bij verschillende omgevingstemperaturen. Meetdata zijn ‘ruwe’ meetdata, d.w.z. deze zijn niet genormaliseerd met de voor RDE ontwikkelde tools EMROAD en CLEAR.

In het kader van het emissiegedrag van de geteste voertuigen zijn de resultaten als indicatief aan te merken. De voor de RDE-trips gebruikte SEMS-meetapparatuur is een tool voor screening van praktijkemissies die niet ontworpen en gecertificeerd is voor typegoedkeuringsdoeleinden.

De metingen aan deze twee voertuigen zijn onderdeel van een lopend project. In dit project onderzoekt TNO namens het Ministerie van Infrastructuur en Milieu praktijkemissies van personen- en bestelwagens. Binnen dit onderzoek is het tweede geteste voertuig ook ingezet voor vaststelling van rijgedrag van voertuigen in de praktijk in verschillende Europese landen.

Summary

This report presents results of on-road measurements of the NO_x emissions of two Mercedes C220 Bluetec Euro 6 diesel vehicles at different ambient temperatures. The results are to be interpreted as an example of the ways in which on-road NO_x emissions of diesel vehicles may depend on ambient temperature. Results are valid for this specific vehicle model only, and cannot be extrapolated to other vehicles. Other vehicle models may behave very differently.

Two Mercedes C220 Euro 6 diesel vehicles with identical type approval were tested. In Figure S1 the NO_x emissions of the two vehicles at different ambient temperatures are shown. Going from 15 °C down to 5 °C the on-road NO_x emissions on average increase by a factor of 7.

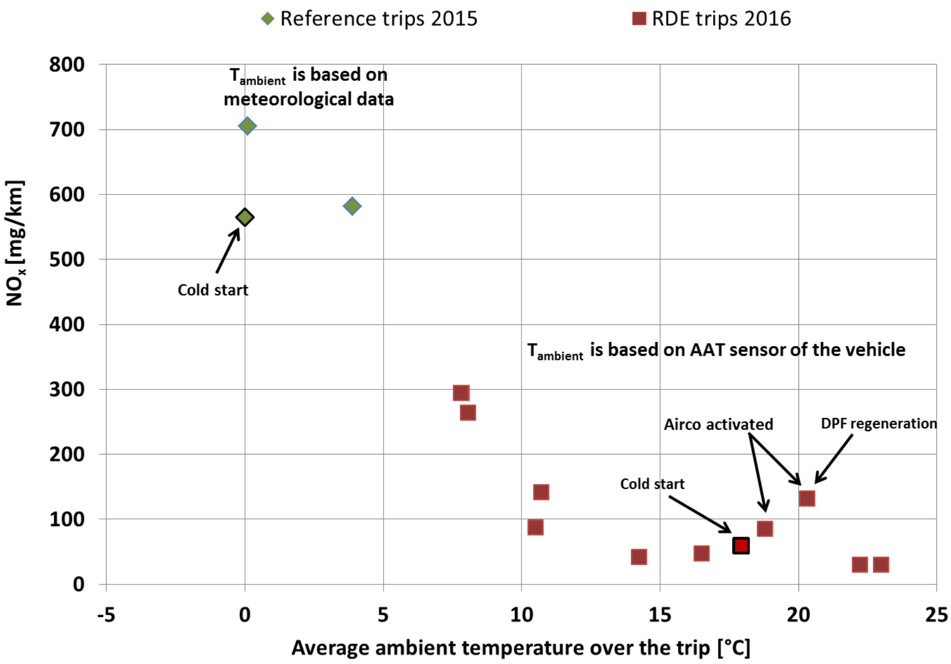


Figure S1 Average NO_x emissions of two Mercedes C220 Euro 6 diesel vehicles in a reference or RDE-compliant trip at different ambient temperatures. The measurement data are ‘raw’ test trip emissions, i.e. they are *not* normalised using the RDE tools EMROAD or CLEAR.

With respect to the emission behaviour of the tested vehicle model the results are to be considered as indicative only. The SEMS equipment , applied in the RDE trips, is a screening tool for measuring on-road emissions and is not designed and certified for type-approval purposes.

The vehicle type, for which results are presented, was tested in the context of an on-going, more elaborate measurement program to investigate real-world emission behaviour of light duty vehicles, carried out by TNO on behalf of the Dutch Ministry of Infrastructure and the Environment. In the context of that program the second vehicle was also used to record the variation in real-world driving behaviour across different European countries.

Contents

1 Introduction

1.1 Context

To minimize air pollutant emissions of light-duty vehicles, in 1992 the European Commission introduced the Euro emission standards. In the course of time, these standards have become more stringent. Currently-produced light-duty passenger vehicles of category M must comply with the Euro 6b standard. The Euro 6c standard, that further limits the emissions of light-duty vehicles, will become mandatory in 2017.

Commissioned by the Dutch Ministry of Infrastructure and the Environment, TNO regularly performs emission measurements within the “in-use compliance program for light-duty vehicles”. In recent years TNO has performed real-world tests on multiple Euro 6 diesel vehicles.

Over the last year, the interest in real-driving emissions of light-duty diesel vehicles has increased considerably. One of the parameters that is found to have a major impact on NO_x emissions of vehicles is the ambient temperature. In the current type-approval test procedure, carried out in the laboratory on a roller bench, the temperature of the test cell must be between 20 and 30 °C. At around 12 °C, however, the average ambient temperature in most European countries is significantly lower.

Based on the emission measurements, performed in the “in-use compliance program for light-duty vehicles”, TNO develops and annually updates vehicle emission factors that represent the real-world emissions of a range of vehicle categories under different driving conditions. Vehicle emission factors are used for emission inventories and air quality monitoring. TNO is one of the few institutes in Europe that perform independent emission tests. Over the last years the results of these tests have provided evidence of the growing difference between legislative emission limits and real-world emission performance of cars.

1.2 Objectives and scope

In this report the test results of two vehicles of the same Euro 6 diesel passenger car model (Mercedes C220 Bluetec diesel, model year 2016) are presented and discussed.

The objective of the tests, of which the results are presented here, is to give insight in the influence of ambient temperature on the NO_x emission behaviour of a Euro 6 diesel vehicle.

The results are to be interpreted as an example of the ways in which on-road NO_x emissions of diesel vehicles may depend on ambient temperature. Results are valid for this specific vehicle model only, and cannot be extrapolated to other vehicles. Other vehicle models may behave very differently.

2 Method

In this chapter the vehicle specifications, test trips, measuring equipment and test programs are described. An extensive and detailed explanation of the applied test methods is reported in the TNO report 2016 R11178 *Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme.*

2.1 Vehicle specifications

Table 1 lists the specifications of the two test vehicles. The first vehicle was tested on the road in 2015 with PEMS equipment, the second in 2016 with SEMS emission measurement equipment[1].

Table 1 Specifications of the two Mercedes C220 Bluetec Euro 6 diesel vehicles

Test period	**February 2015**	**May 2016**
Body type	Sedan	Sedan
Swept volume engine [dm^3]	2.143	2.143
Maximum Power [kW]	125	125
Vehicle mass empty [kg]	1470	1470
Vehicle mass [kg]	1590	1590
Estimated test mass [kg]	1990	1680
Tyre size	225/50R17 94H	225/50R17 94H
Emission control technology	EGR + DPF + SCR*	EGR + DPF + SCR*
VIN	WDD 205004 1F 007336	WDD 205004 1F 001337
Odometer [km]	20,000	19,000
Picture	Figure 1	Figure 2

*EGR: Exhaust Gas Recirculation; DPF: Diesel Particulate Filter; Selective Catalytic Reduction

Figure 1 Mercedes C220 Euro 6 diesel of the PEMS test programme (2015)

[1] See section 2.3 and TNO 2016 R11178, “Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme”, V.A.M. Heijne et al., 2016

Figure 2 Mercedes C220 Euro 6 diesel of the SEMS test programme (2016)

2.2 On road test trips

Table 2 provides general information on the test trips driven with the two test vehicles. From 2010-2015 TNO performed on-road tests in so-called 'reference trips'. In late 2015 TNO has started the development and execution of RDE-compliant trips. Overall the two trips have highly comparable characteristics.

Table 2 Test trip specifications

	TNO Reference trip Helmond	**TNO RDE-trip Delft**
Type	Urban, rural and highway	Urban, rural and highway
Cold/Hot start	Cold and hot start	Hot start
Distance [km]	73.5	72.7
Duration [min]	85 - 95	88 - 101
Av. speed [km/h]	55 (excluding idle time)	50-54 (excluding idle time)
Load [-]	Driver + test engineer + test equipment	Driver + test equipment
Test equipment	PEMS	SEMS

2.3 Test equipment

For type approval purposes, on-road tests of vehicles are carried out with a Portable Emission Measurement System (PEMS) which measures CO, CO_2, THC, NO and NO_2 emissions (see Figure 3). PEMS is a stand-alone system, analyser-based, relatively accurate and expensive. Highly-qualified personnel is needed for good operation.

For emission screening purposes, TNO has developed a simpler and less intrusive Smart Emission Measurement System that is sensor-based (see Figure 4). It measures NO_x and O_2 volumetric concentrations. In addition, some data are taken from the CAN-bus of the vehicle which are used to convert measured concentrations into absolute emissions (g/km). The quality of these CAN-bus data is generally unknown. In several experiments the accuracy of SEMS has been investigated, and has shown to be +/- 10%. However, the reproducibility and repeatability are good. The equipment allows TNO to test vehicles extensively for longer periods at limited costs to obtain in-depth insight into the real-world emission behaviour as a function of a wide but realistic range of real-world use conditions.

Figure 3 Portable Emission Measurement System (PEMS)

Figure 4 Smart Emission Measurement System (SEMS)

2.4 The first emission test program of February 2015

In February 2015 TNO performed on-road emission tests and chassis dynamometer tests on the first Mercedes C220 with a 125 kW Euro 6 diesel engine.

Chassis dynamometer tests were performed in the facilities of Horiba in Oberursel, Germany. Tests were carried out with different driving cycles and with warm and cold starts.

On-road emission tests were carried out using a Portable Emission Measurement System (PEMS). In and around the city of Helmond, the Netherlands, three reference trips (see Table 2) were driven at ambient temperatures ranging between 0 and 5 °C.

2.5 The second emission test program of May 2016

In order to investigate the emission behaviour of this vehicle type on the road at higher ambient temperatures, a second test program was performed with a second vehicle of the same make and model in May 2016. A standardised trip compliant with the requirements of the Real Driving Emission tests (see Table 2), was driven eight times in and around the city of Delft, the Netherlands within a period of 29 days. In this period the ambient temperature varied between 8 and 23 °C. The NO_x

emissions were measured using TNO's Smart Emission Measurement System (SEMS).

This second test program was part of a broader test program of this vehicle. More test results of this vehicle are reported in the TNO report 2016 R11177, *NO_x emissions of 15 Euro 6 diesel cars.*

3 Emission test results of the two vehicles

In the seven chassis dynamometer tests of the 2015 test programme - in the laboratory at 23 °C - the NO_x emissions were found to be 36 - 51 mg/km; well below the limit value of 80 mg/km (see Figure 5). These tests included the type approval test cycle carried out with a cold start (NEDC-c) as well as with a hot start (NEDC-h), the WLTC and CADC real-world test cycles and a constant speed test.

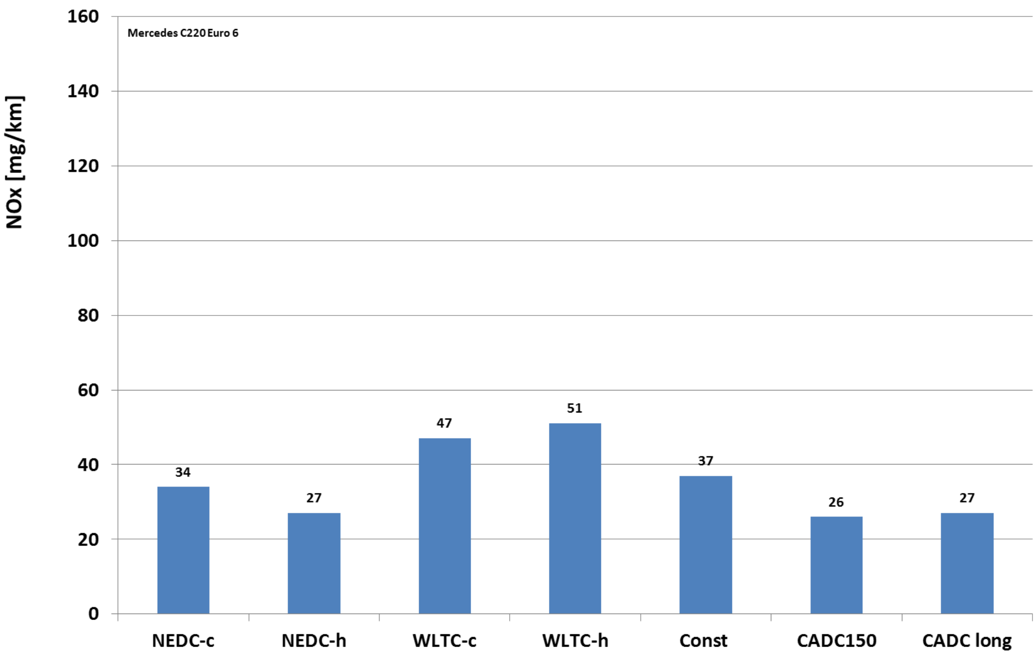


Figure 5 Chassis dynamometer test results of a Mercedes C220 Euro 6 diesel at an ambient temperature of 23 °C

In Figure 6 the on-road NO_x emissions of the two tested vehicles at different ambient temperatures are shown.

For the reference trips, driven with the vehicle tested in 2015, ambient air temperature is based on data from a nearby national meteorological station. During these trips only the Inlet Air Temperature (IAT) was directly recorded. This showed significantly higher temperatures (0 - 21 °C) than the ambient air temperatures (0 - 5 °C) obtained from meteorological data. This may have been the result of the inlet air being heated by the engine. The inlet air flow can, for example, depend on the settings of the grill vanes which are varied for aerodynamic properties.

For the RDE trips, driven with the second vehicle in 2016, the reading from the vehicle's own Ambient Air Temperature sensor (AAT) is used.

Figure 6 shows that above 20 °C the on-road NO_x emissions of the vehicle in RDE trips are 30 to 31 mg/km, which is below the type approval limit value of 80 mg/km. The use of the air conditioning and a DPF regeneration yield an increase of the NO_x emissions up to 132 mg/km. At a lower ambient temperature of 10 °C, the NO_x

emissions increase to 100 to 150 mg/km. At lower temperatures, however, NO_x emissions on the same test trip are significantly elevated. At 0 °C the NO_x emissions of this vehicle are 565 to 705 mg/km. The detailed test results are shown in Appendix A.

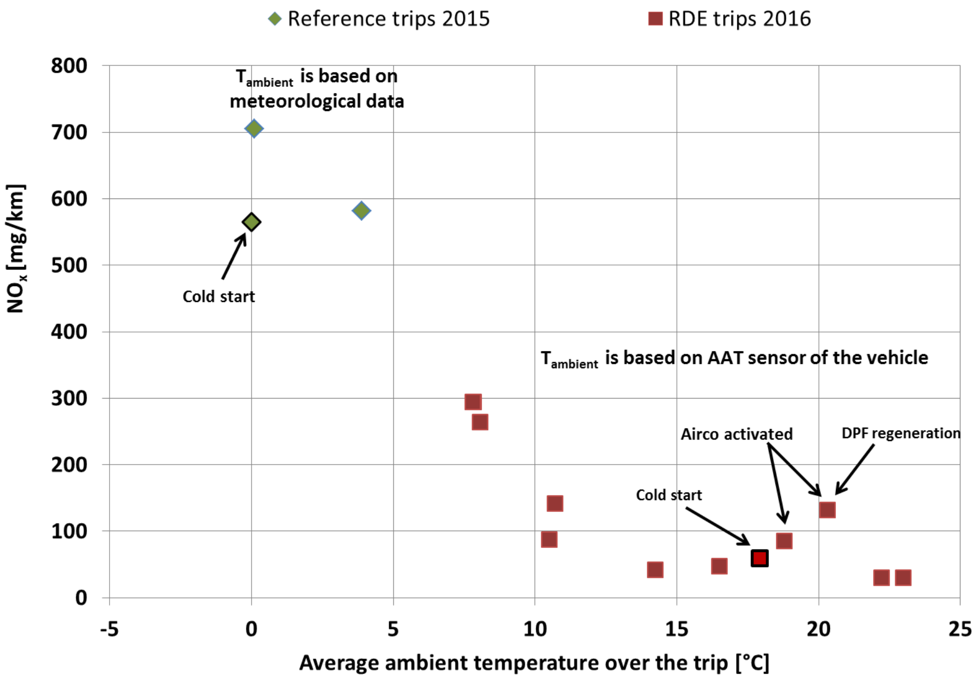


Figure 6 Average NO_x emissions of two Mercedes C220 Euro 6 diesel vehicles in a reference or RDE-compliant trip at different ambient temperatures. The measurement data are 'raw' test trip emissions, i.e. they are not normalised using the RDE tools EMROAD or CLEAR.

Daimler has stated that the higher NO_x emissions at lower ambient temperatures are the result of gradually reducing the use of and/or shutting off emission control technology to protect the engine. Our test results confirm this explanation as a seemingly gradual but large increase in emissions is observed from the low level at 20 to 30 °C to high emissions at temperatures below 10 °C.

In Figure 7 the on-road CO_2 emissions of the two tested vehicles at different ambient temperatures are shown. The figure shows that in the range of 8 to 20 °C the on-road CO_2 emissions of the vehicle in the RDE trips are 127 - 138 mg/km. The use of the air conditioning and a DPF regeneration yield an increase of the CO_2 emissions up to 152 g/km. In reference trips at a lower ambient temperature of 0 to 5 °C, the CO_2 emissions increase to 156 - 165 mg/km. This increased CO_2 emission is mainly caused by the relative high test mass of 1990 kg of the first vehicle (PEMS + test driver and test engineer) instead of 1680 kg of the second vehicle (SEMS + test driver). Another cause of the higher CO_2 emissions is the low ambient temperature which causes a higher air resistance.

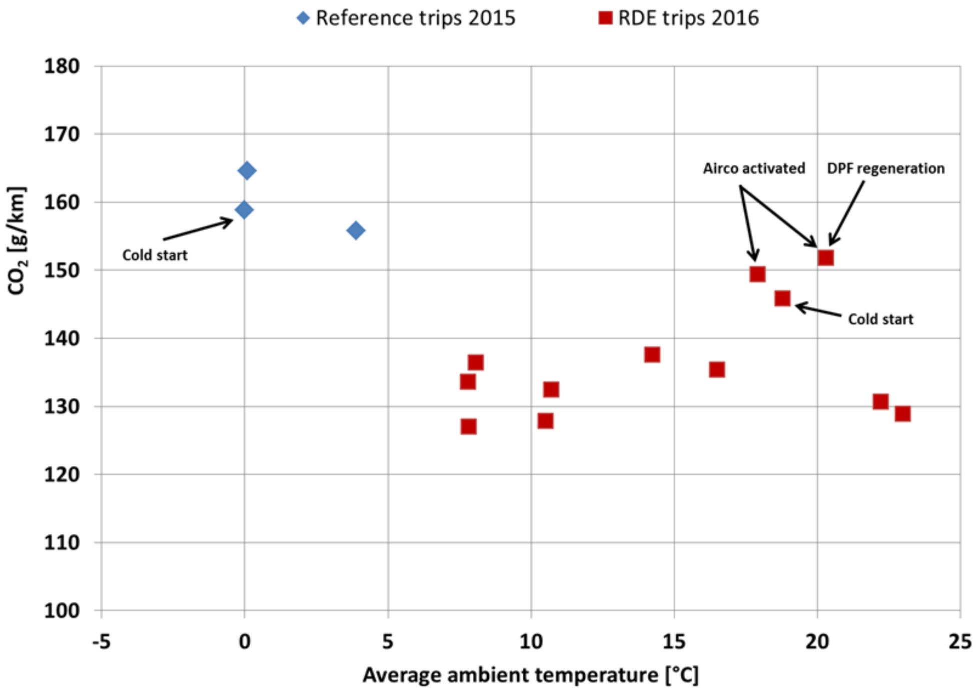


Figure 7 Average CO_2 emissions of two Mercedes C220 Euro 6 diesel vehicles in a reference or RDE-compliant trip at different ambient temperatures.

4 Discussion

The initial tests in 2015 on a Mercedes C220 diesel vehicle showed high emissions on a trip driven at low temperatures (0-5 °C). From these tests no conclusions could be drawn on the extent to which the observed high emissions correlated with the low ambient temperature.

The subsequent 2016 tests with a vehicle of the same make and model show lower emissions at higher temperatures, with the emissions gradually decreasing as the ambient temperature reaches 20 °C. Above 20 °C, the vehicle meets the RDE requirements of phase 2 in this test. At these temperatures, it even meets the type-approval limit of 80 mg/km in normal on-road driving.

The initial test were performed on the road using the TNO Reference Trip to cover normal on-road driving conditions. The tests in 2016 used the TNO RDE trip, defined within the boundaries of the oncoming RDE legislation.

Based on available specifications of the two vehicles, it is concluded that both vehicles have the same engine and emission control technology. The emission data of the different tests are well in line. Combining the results shows a smooth transition from low on-road emissions at 20 °C and above to more than tenfold higher emissions when the ambient temperature approaches 0 °C.

It should be noted that the ambient temperatures of 0 to 5 °C, that occurred during the on-road tests in 2015, are not extreme temperatures for the Netherlands. Moreover, from investigations by JRC for the RDE legislation, it is clear that 0 to 30 °C can be considered to be normal temperatures for Europe.

In the Reference Trip of 2015, only the Inlet Air Temperature (IAT) was recorded, with significantly higher temperature readings (0 to 21 °C) than the ambient air temperatures (0 to 5 °C) from a nearby national meteorological station. This may have been the result of the inlet air being heated by the engine. The inlet air flow can depend on the varying settings of the grill vanes.

Furthermore, the average CO_2 emissions in the Reference Trips were 21% higher than in RDE trips (159.7 versus 131.6 g/km). This was mainly caused by the higher test weight of the first vehicle, resulting from the fact that it was equipped with PEMS test equipment, weighing around 200 kg, and the presence of a test engineer in the vehicle during these tests. The weight of the SEMS system is around 10 kg, and tests with SEMS do not require the presence of a test engineer.

5 Conclusion

The two Mercedes Benz C 220 Bluetec diesel vehicles perform well with respect to on-road NO_x emissions at ambient temperatures of 20 °C and above. At lower temperatures, however, NO_x emissions are much higher, exceeding the type approval limit values of 80 g/km by a factor of 7 to 9. In 2015 the manufacturer explained that this is caused by a reduced operation of the applied emission control technologies to protect the engine when operated at lower temperatures.

The results of the recent tests are consistent with the explanation of reduced operation of emission control technology, as they show a gradual but large increase of the emissions when the ambient temperature decreases from 20 to 0 °C.

Given the average temperature in the Netherlands of 10 to 11 °C, on-road test results measured at ambient temperatures above 20 °C as well as type approval test results obtained in the lab on the NEDC at temperatures between 20 and 30 °C cannot be considered representative for the real-world emission performance of vehicles in the Netherlands.

6 Signature

Delft, 4 October 2016

TNO

Peter van der Mark
Project Leader

Gerrit Kadijk
Author

A Detailed test results

Vehicle	Test	Trip data							Vehicle data (CAN bus)				
Sample	mass	Test	Date	Start time	Trip type	Length	Duration	Speed	Tair sensor	Tair	Tair	Tair	Tair
	[kg]			hh:mm		[km]	[s]	[km/h]	location	[°C]	[°C]	[°C]	[°C]
								average		Average	St, dev,	Min,	Max,
1	1990	1	4-2-2015	15:27	REF	73.2	5561	47.4	IAT	8.0	2.0	4	12
1	1990	2	5-2-2015	10:30	REF	73.6	5268	50.3	IAT	3.8	4.0	0	21
1	1990	3	6-2-2015	10:10	REF	73.2	5382	48.9	IAT	3.2	2.6	0	12
2	1680	4	14-5-2016	10:44	RDE	72.7	5690	46.0	AAT	10.7	1.2	7	16
2	1680	5	14-5-2016	16:06	RDE	72.8	5459	48.0	AAT	10.5	0.9	8	15
2	1680	6	15-5-2016	4:34	RDE	74.3	5654	47.3	AAT	7.8	0.7	6	15
2	1680	7	15-5-2016	6:45	RDE	72.8	5374	48.8	AAT	8.1	1.1	6	15
2	1680	8	16-5-2016	6:24	RDE	72.8	5726	45.8	AAT	7.8	0.8	6	13
2	1680	9	20-5-2016	12:05	RDE	72.7	5728	45.7	AAT	16.5	0.8	15	21
2	1680	10	21-5-2016	14:21	RDE	77.5	6060	46.0	AAT	22.2	0.8	20	25
2	1680	11	21-5-2016	16:13	RDE	77.5	5722	48.8	AAT	23.0	0.7	21	25
2	1680	12	8-6-2016	15:45	RDE	71.8	6486	39.9	AAT	18.8	1.8	16	26
2	1680	13	10-6-2016	9:18	RDE	72.8	6706	39.1	AAT	17.9	2.1	15	24
2	1680	14	11-6-2016	9:47	RDE	72.7	5598	46.8	AAT	14.2	0.7	13	18
2	1680	15	11-6-2016	16:15	RDE	72.7	5915	44.2	AAT	20.3	1.0	18	26

Metereological data KNMI				Wind	Wind				Test result			Cold start	Airco	DPF
Test	Location	Start	Tamb	Direction	Speed	Tamb	Tamb	Tamb	NOx	CO2	NH3		activated	regen
		time	[°C]	[°]	[m/s]	[°C]	[°C]	[°C]	[mg/km]	[g/km]	[mg/km]			
	KNMI	hh:mm	Actual	Actual	Actual	24h	24h	24h	Average	Average	Average			
			ave 1h	ave 1h	ave 1h	ave	min	max						
1	Eindhoven	15:27	3.9	310	3	-0.3	-5.2	4.9	581.0	155.8		N	N	N
2	Eindhoven	10:30	0.0	60	4	-1.2	-6.0	0.7	565.0	158.8		Y	N	N
3	Eindhoven	10:10	0.1	50	8	-0.8	-2.6	2.4	705.0	164.6		N	N	N
4	Rotterdam	10:44	10.7	330	6	8.7	5.4	12.1	141.8	132.5	0.2	N	N	N
5	Rotterdam	16:06	9.1	320	7	8.7	5.4	12.1	88.0	127.9	0.3	N	N	N
6	Rotterdam	4:34	6.3	310	4	8.2	4.3	11.8	294.0	127.0	0.2	N	N	N
7	Rotterdam	6:45	9.4	310	5	8.2	4.3	11.8	264.1	136.4	0.2	N	N	N
8	Rotterdam	6:24	7.9	10	1	9.3	4.2	13.1	294.8	133.6	0.3	N	N	N
9	Rotterdam	12:05	17.0	250	6	14.0	11.7	18.1	47.0	135.4	1.7	N	N	N
10	Rotterdam	14:21	22.8	210	8	18.3	12.2	23.3	30.6	130.7	3.4	N	N	N
11	Rotterdam	16:13	21.8	190	6	18.3	12.2	23.3	29.6	128.9	2.9	N	N	N
12	Rotterdam	15:45	15.5	340	5	15.8	12.6	20.9	85.5	145.9	1.2	N	Y	N
13	Rotterdam	9:18	18.8	350	1	15.9	8.7	20.9	59.0	149.4	2.5	Y	N	N
14	Rotterdam	9:47	15.1	90	2	16.0	12.6	20.2	42.3	137.6	2.2	N	N	N
15	Rotterdam	16:15	19.3	40	2	16.0	12.6	20.2	131.6	151.8	29.5	N	Y	Y