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TNO report

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Study of NO_x emission behaviour of a Jeep Grand Cherokee Euro 5a diesel

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Summary

In an emission study reported by the Netherlands Vehicle Authority (RDW) in July 2017 [RDW 2017], the first exploratory emission tests for the Jeep Grand Cherokee Euro 5a were carried out. The test results concerning the measured NO_x emissions gave rise to further research.

In 2018, the Netherlands Vehicle Authority (RDW) commissioned TNO to carry out an emission study of the Jeep Grand Cherokee Euro 5a diesel.
The goal of the study was to map the Jeep Grand Cherokee emission behaviour, measured with 2 different engine calibrations (C1 & C2).
To this end, several partial objectives were formulated and emission measurements were carried out on a test track of the RDW, on a dynamometer and on public roads.

When taken together, the results of these measurements provide a good overview of the emission behaviour of the tested vehicle and the differences in emissions before and after the update of the engine calibration software.
The partial conclusions based on the performed measurements have been included below.

Partial conclusion 1:
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 0.5 to 10 times higher than the driving resistance curve determined by the manufacturer.
The absolute difference in driving resistance is constant over the speed range of 10-130 km/h and is about 600-700 N. This difference is largely caused by the turns of the test track.

Partial conclusion 2:
Two Jeep Grand Cherokee Euro 5 diesel vehicles with the original engine calibration C1 were tested. The first was tested in the RDW study of 2017 and the second was tested in this study. In both cases, the emission tests on the test track showed that the vehicles significantly exceed the NO_x limit value of 180 mg/km and have similar emission behaviour.

Partial conclusion 3:
Based on NEDC testing with a cold start of the Jeep Grand Cherokee Euro 5 diesel with the original engine calibration C1, which was performed on the test track in different ambient temperatures, it appears that the NO_x emission rises from approx. 1000 to more than 3500 mg/km when the ambient temperature drops from 21 to 2 °C. The corresponding CO_2 emission rises from 281 to 358 g/km.
This indicates that the NO_x and CO_2 emissions of the Jeep Grand Cherokee Euro 5 diesel with its original engine calibration are heavily dependent on the ambient temperature.

Partial conclusion 4:
In the NEDC testing with the original engine calibration C1 and a hot start on the test track, the NO_x emissions were up to twice as high as in the NEDC test of the cold start on the test track (1874 versus to 970 mg/km).

On the dynamometer, the emissions are almost eight times higher (1498 versus 199 mg/km). Therefore, there are differences in NO_x emissions in NEDC testing between cold and hot starts and there are also differences in NO_x emissions measured between the dynamometer and the test track.
The differences in NO_x emissions are primarily caused by the different amounts of exhaust gas that flow back to the engine (EGR), caused by the active control of the EGR valve by the engine operating system. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.

Partial conclusion 5:
In UDC tests with engine calibration C1 and a cold start, it appears that over time the NO_x emissions abruptly rise from approximately 250 to 1750-2750 mg per ECE cycle. A similar rise in NO_x emissions was measured in a test with a constant speed of 50 km/h. The rise in NO_x emissions is primarily caused by the applied method of controlling the EGR system. The timing of this sudden rise of NO_x emissions varies between the different tests, the cause of this is unknown. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.
In UDC tests with a hot start, the NO_x emissions are consistent at a level between 2700 and 3000 mg per ECE cycle and the EGR recirculation appears to be stable.

Partial conclusion 6:
UDC tests with engine calibration C1 and a cold start that were performed on the test track and on the dynamometer show a similar trend in NO_x emissions. After a number of ECE cycles, the NO_x emissions suddenly increase from about 200 to 2000 mg per ECE cycle. The absolute NO_x and CO_2 emissions on the dynamometer are somewhat lower than on the test track. It must be noted that the engine load was lower on the dynamometer than on the test track.

Partial conclusion 7:
The NO_x emission behaviour of the tested vehicle is not influenced by the type of power source used for the Smart Emission Measurement System (SEMS) and the driver aid.
Using the battery of the vehicle or an external battery as the power source for the SEMS and the driver aid does not seem to have any measurable influence on the NO_x emissions.

Partial conclusion 8:
In an NEDC test with the original engine calibration C1 which was carried out according to the type-approval test requirements, the CO_2 emission was 241 g/km. This is 7% higher than the measured type-approval test value. The measured NO_x emission is 199 mg/km, this is 11% above the Euro 5 limit (180 mg/km). Therefore, the measurements slightly exceed the Euro 5 limits.

Partial conclusion 9:
From the results of the NEDC tests with the original engine calibration C1 conducted on the dynamometer with different resistance curves and on the test track, it appears that the CO_2 and NO_x emissions (significantly) increase when the resistance increases.

On the test track, testing is carried out with the highest driving resistance. An increase in the driving resistance results in an increase in the engine load, which, in this testing programme, leads to an increase in CO_2 emissions from 241 to 283 g/km (+ 17%) and an increase in NO_x emission from 199 to 983 mg/km (+ 394%).

Partial conclusion 10:
The absolute CO_2 and NO_x emissions of this Jeep Grand Cherokee, measured by the SEMS, are higher than the stated value determined by the statutory measurement method on a dynamometer. The relative deviations are 11-13% for CO_2 and 17-23% for NO_x and these are fairly consistent across significantly different emission levels in the five tests conducted. For the partial conclusions in this study, the abovementioned deviations of the SEMS have no impact because all the measurements were carried out using the SEMS and the measured deviations for the different emission levels are constant.

Partial conclusion 11:
The NO_x emissions of the Jeep Grand Cherokee Euro 5a diesel decreased considerably after the update of the engine calibration (C2).

This was established in the following tests:

1. In the NEDC type-approval test on the chassis dynamometer, with both engine calibrations and with a cold start, the NO_x emissions are fairly constant at 199 and 145 mg/km and around the limit value of 180 mg/km.
   On the test track, this NEDC test with a cold start with both engine calibrations was carried out with an ambient temperature of 24 and 18 °C, resulting in a decrease in NO_x emissions from 1319 to 376 mg/km with engine calibration C2.
2. In the RDE tests with a hot start that were performed on public roads, the NO_x emissions decreased from 1807-2170 to 599-774 mg/km after the update of the engine calibration. Starting conditions (cold start and hot start) with engine calibration C2 only have a very small impact on the NO_x emission levels in RDE testing.
3. In UDC tests with engine calibration C1 and a cold start that were conducted on the dynamometer and on the test track, the NO_x emissions increase abruptly 1500 seconds after the cold start, from approximately 250 mg per ECE cycle to 1750-2750 mg per ECE cycle. With engine calibration C2, this NO_x increase is much smaller at approx. 170 to 500 mg per ECE cycle.

In an NEDC type-approval test on the chassis dynamometer with a cold start, the NO_x emissions with the two engine calibrations are around the limit value of 180 mg/km. In daily practical conditions on public roads, the average NO_x emissions with engine calibration C2 decrease to approximately 700 mg/km (approx. 65% reduction in comparison to 2000 mg/km with engine calibration C1).

Partial conclusion 12:
Just like engine calibration C1, the emission behaviour of engine calibration C2 is not constant. The NO_x emissions in UDC tests increase with engine calibration C2 after approximately 1500 seconds, from 170 to 500 mg per ECE cycle, while the added quantity of EGR decreases.

Contents

1 Introduction

1.1 Background

In a previous emission study from RDW that was reported on in July 2017 [RDW 2017], the first exploratory emission tests were conducted for a Jeep Grand Cherokee Euro 5a diesel. The emission tests were carried out on an RDW test track at RDW in Lelystad at an ambient temperature of 16 to 25 °C as well as on a dynamometer at 25 °C. The measured NO_x emissions on the test track varied from 970 to 2195 mg/km, see Figure 1-1.

These appear to be 7 - 12 times higher than the allowed NO_x emissions in the type-approval test for this vehicle model. Three tests were also carried out on a dynamometer. NO_x emissions of 220 mg/m were only measured in the NEDC type-approval test. In the other two tests, the NO_x emissions were 1630 and 1646 mg/km, respectively.

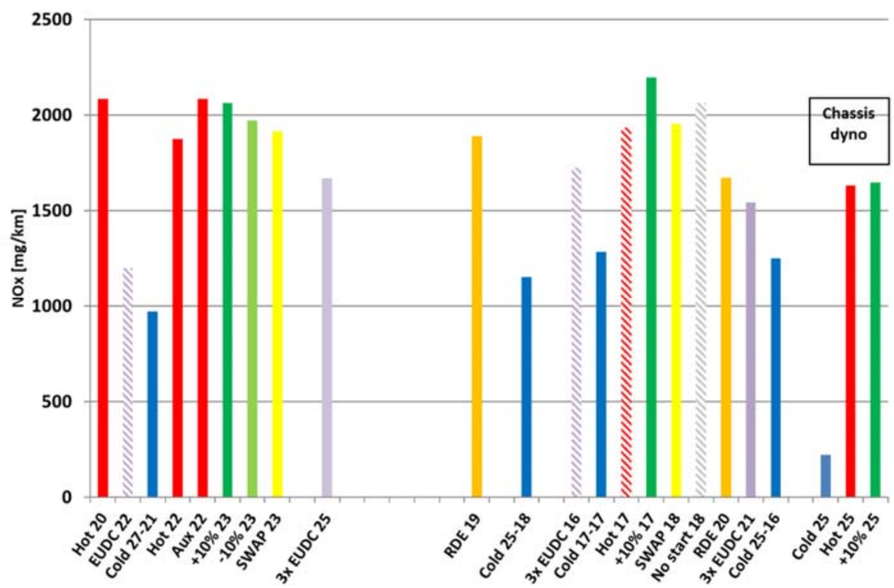

Figure 1-1: NO_x test results from the first exploratory measurements of a Jeep Grand Cherokee Euro 5a diesel in 2017. Source: [RDW 2017].

RDW discussed the test results with the manufacturer, Fiat Chrysler Automobiles (FCA), after which the following was reported:

“At FCA, it was found that the values were very high in comparison to the type-approval test. For the Jeep Wrangler, there is sufficient evidence that the measures taken by FCA were necessary to protect the engine. The NO_x emissions of the Jeep Grand Cherokee are multiple factors higher when the NEDC test is conducted with a hot start in comparison to when the same test is conducted with a cold start. The necessity to protect the engine has been insufficiently demonstrated here. The Public Prosecutions Service (OM) has been notified of this case.

At the request of RDW, the FCA will roll out an update for the Jeep Grand Cherokee in July 2017, with the aim of reducing emissions in practice. The update will be evaluated by RDW.

RDW has commissioned TNO to conduct an emission study of the Jeep Grand Cherokee Euro 5a diesel with the original and updated engine calibration. The most important reason for this follow-up study is to map out the NO_x emission behaviour of this vehicle in regard to the type-approval test for both engine calibrations. The measured emission behaviour with the original engine calibration shows high NO_x emissions under practical conditions.
Mapping the actual emission behaviour is one of the elements necessary to be able to determine if an illegal manipulation instrument is present. It must be emphasised that this TNO study does not make a statement regarding whether the deviant behaviour can be viewed as a manipulation instrument (defeat device).

This report presents the measurements of the actual emission behaviour of the same Jeep Grand Cherokee Euro 5a diesel with the two engine calibrations: the one from before and after the software update. This vehicle model received a European type-approval (e4 * 715/2007 * 692/2008A * 0242 * 00) from the Netherlands Vehicle Authority on 28 January 2011. Euro 5a means that the emissions need to meet certain standard values.

1.2 Objectives

The main objective of this research is to map out the NO_x emission behaviour of a Jeep Grand Cherokee Euro 5a diesel with the original engine calibration (C1) and with the engine calibration that has been updated by FCA (C2), previously referred to as “software update”.

To this end, this study has the following ten partial objectives:
1. Verification of the exhaust emissions in the type-approval test on a dynamometer.
2. Verification of the driving resistance curve.
3. Determination of the effect of different driving resistance curves on exhaust emissions.
4. Determination of the exhaust emissions in a type-approval test and in other emission tests on a test track.
5. Investigation into the EGR regulation strategies used.
6. Investigation into the emission behaviour during the warming up phase.
7. Determination of practical conditions in Real Driving Emission (RDE) tests on public roads.
8. Determination of the effect of the two different engine calibrations on the vehicle emissions.
9. Determination of the effect of different ambient and cooling water temperatures on the vehicle emissions for the two engine calibrations.
10. Investigation into the emission behaviour of the vehicle with both engine calibrations in relation to the (cumulative) parameters, such as operating time, fuel consumption, distance travelled and speed.

It must be emphasised that the study does <u>not</u> aim to investigate the presence of a manipulation instrument (defeat device) in the vehicle.

Therefore, no conclusions will be made on this in the report. The report does provide information for the further handling of such a question.

1.3 Approach

In this research, the test activities were conducted on one Jeep Grand Cherokee Euro 5a diesel. The vehicle is tested with two different engine calibrations.
The research is based on emission tests that were conducted on an RDE test track in Lelystad and on a dynamometer at the Horiba factory in Oberursel.
A few RDE tests were also conducted on public roads. The schedule of the conducted activities is shown in Table 1-1.

Table 1-1: Schedule of research activities

Date of period	Activity
March 2018	Instrumentation vehicle
April - July 2018	Conducting emission tests on test track part 1
14 - 27 August 2018	Dynamometer test programme part 1
28 August 2018	Software update calibration
29 - 31 August 2018	Dynamometer test programme part 2
September - October 2018	Conducting emission tests on the test track part 2
November 2018 - January 2019	Report

1.4 Reading guide

In chapter 2 of this report, general information will first be provided on the different parts of an emission test procedure, given its specialised nature.
Chapter 3 describes the data of the tested vehicle, the test equipment used, the test locations, the test cycles and the fuel used.
The test results are reported in chapter 4. Following a discussion in chapter 5, the conclusions are presented in chapter 6. The report also includes Appendices A to E.

2 Technical background and interpretation

Given the specialised nature of emissions tests on road vehicles, this chapter will explain the different parts of an emissions test. In certain parts of this chapter, reference is made to the researched vehicle (Jeep Grand Cherokee).
The information in this chapter is intended as background information.
The description of the actual research can be found in chapters 1 and 3 to 6.

2.1 Emission test methods

Emission tests can be conducted in test labs or on the road.
These two test methods are used for different goals:

- In test labs, dynamometers allow for test conditions to be set and kept constant. The measuring equipment is used in a fixed setup, which results in defined measuring conditions, ensuring relatively high accuracy. This results in high reproducibility of emission tests and enables comparisons to be made between tests carried out in different labs.
- On the road, conditions can vary significantly in a short space of time, due to wind force, direction of travel, inclination angles of the road, external temperatures and driving style (calm and sporty). Because of this, the results of road tests show more variation than those on a dynamometer. Emissions in practice road conditions can have a wider spread and are, therefore, difficult to reproduce.
- Attempts can be made to simulate the laboratory test on the road. This was done in this research. For that reason, a lot of attention was given to the factors that cause the variation between laboratory conditions and deviations from these.

Applying the statutory emission measurement method on the road requires an increase in emission requirements. Up to 2017, vehicles with a type-approval for emissions were only tested on a dynamometer. This is also the case for the Jeep Grand Cherokee Euro 5a diesel in this study.
New vehicle models that will be released after 1 September 2017 with a Euro 6d temp type-approval will have to undergo road emission tests (RDE tests) in the type-approval. But, more importantly, the manufacturer declares that the Euro-6d meets these RDE requirements in a wide range of circumstances and usage situations. An independent party has the option of checking the information on which the type-approval authority must base their decision.

In this study, emission tests were carried out on a dynamometer, on a test track and on the road.

2.2 Type-approval test on a dynamometer

An NEDC (see section 2.3) type-approval test for determining the exhaust gas emissions, which every new vehicle type has to undergo, is conducted on a dynamometer, see Figure 2-1.

The reason for this is that the test conditions are well defined and such a test can, in principle, be conducted by any test laboratory with very similar results, resulting in high reproducibility.

A complete procedure for determining the vehicle emissions contains the following 8 steps:
1. Determining the driving resistance curve of the vehicle on the road (coast-down)
2. Installing the vehicle on the dynamometer
3. Heating the vehicle in the NEDC test cycle to be performed
4. Adjusting the driving resistance curve on the dynamometer
5. Conducting a pre-conditioning cycle
6. Conditioning the vehicle (soak) by leaving the vehicle stationary for 6-30 hours in a conditioned room of 20-30 °C
7. Conducting the NEDC emission test
8. Checking the driving resistance curve

Figure 2-1: A Jeep Grand Cherokee on the dynamometer

2.3 Test cycle in the type-approval

A defined test cycle in the type-approval test is a condition for reproducible test results. For the Jeep Grand Cherokee Euro 5a diesel the NEDC test (New European Driving Cycle) is applicable. In Figure 2-2, the speed pattern of the NEDC test cycle is shown. This test cycle is started with a cold engine and lasts 1180 seconds. A distance of 11 kilometres is covered. The tested vehicle has an automatic gearbox, which means that switching the gears in the emissions test does not require any active action from the test driver.

An NEDC test starts with a cold engine, at which point the coolant and oil temperature are between 20 to 30 °C. This is also called a test with a cold start.
In this study, tests with a so-called "hot start" have been carried out for a variety of reasons. In such tests, the coolant and oil temperatures are approximately 80 °C.

The NEDC test consists of a city cycle, the UDC (Urban Driving Cycle), and an off-road cycle, the EUDC (Extra Urban Driving Cycle).
The UDC is made up of four repetitions of the ECE-15 test, which in turn consists of three separate accelerations up to 15, 35 and 50 km/h. An ECE-15 is 941 metres long. The EUDC test is 6955 metres long.

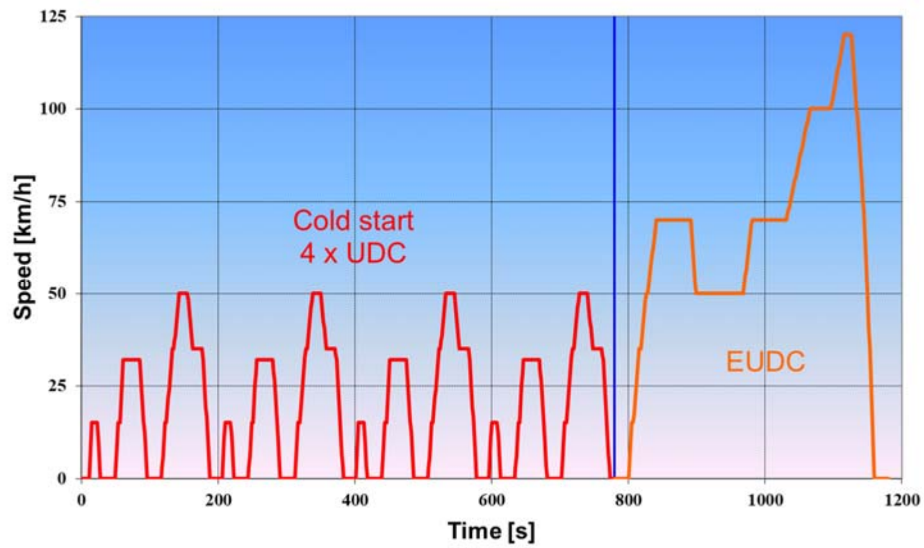

Figure 2-2: NEDC test cycle used in the type-approval on the dynamometer

2.4 Driving resistance and vehicle weight

The driving resistance and weight of the vehicle are simulated on the dynamometer and are established per vehicle type. Both are determined in accordance with statutory requirements/procedures in the type-approval test.

To determine the weight of the vehicle, it is weighed in a defined condition (e.g. with a full fuel tank and an additional fixed weight for the driver). This results in the test weight that is set on the dynamometer.

The driving resistance consists of rolling resistance and air resistance. This is determined on a flat stretch of road by allowing the vehicle to roll from a high speed (130 km/h) to a low speed (10 km/h) while measuring the speed trend over time. In Figure 2-3 an example of the results of this speed measurement are shown. Based on this speed curve, the driving resistance can be calculated which is then set on the dynamometer using three parameters, an example of which is shown in Table 2-1.
The total driving resistance force (F total) at constant speeds (v) is calculated with the following equation.

$$F\ (total) = F0 + F1 * v + F2 * v^2$$

Table 2-1: Example of the adjustment parameters of the driving resistance curve on the dynamometer

Parameter	Unit	Value
F0	[N]	100
F1	[N/(km/h)]	3.50
F2	[N/(km^2/h^2)]	0.035

Determining the driving resistance curve outside according to the legally prescribed procedure generally produces relatively favourable results. This is because the test is often performed under ideal conditions (the driving resistance values are relatively low). Determining the driving resistance curve in more practical situations often provides substantially higher results. This difference is one of the causes of the variations between emissions measured in the laboratory and those measured on the road with the same vehicle.

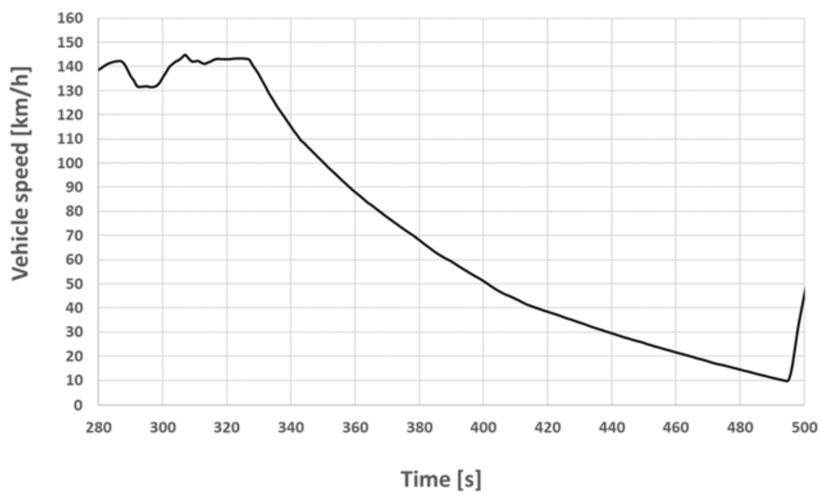

Figure 2-3: Example of a test result to determine the driving resistance of a vehicle This test is repeated a number of times (not shown here).

2.5 Preconditioning test and vehicle conditioning

A type-approval test on a dynamometer requires high reproducibility and repeatability of the emission test. The engine also needs to be cold at the start of the test. To achieve this, the preconditioning and subsequent conditioning of the vehicle have been defined. Preconditioning takes place by driving a test cycle on the dynamometer prior to the type-approval test. For the Jeep Grand Cherokee Euro 5 diesel, a 3*EUDC preconditioning test is applicable, see Figure 2-4. This test cycle lasts 1200 seconds, during which a distance of approximately 21 kilometres is driven.

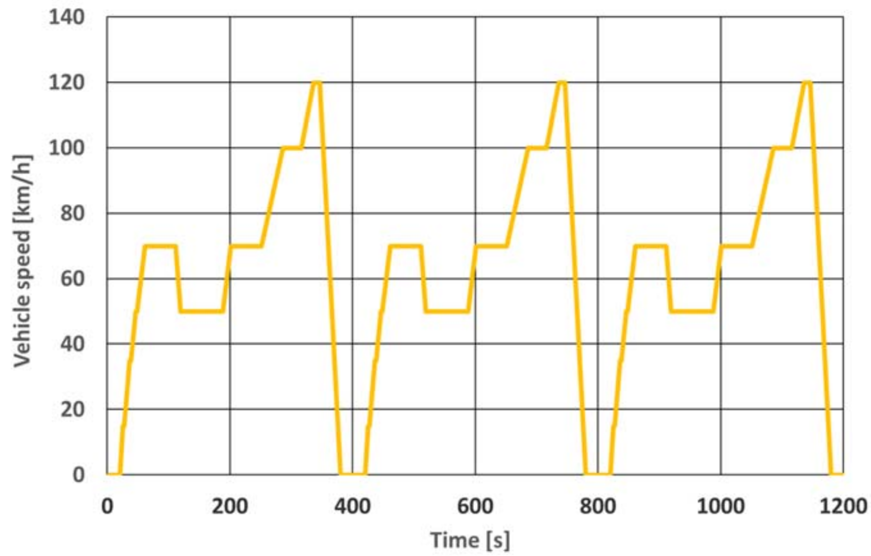

Figure 2-4: Test Cycle (3*EUDC) for preconditioning of the Jeep Grand Cherokee

After preconditioning, the vehicle is placed in a conditioning room with a regulated temperature (20 to 30 °C) and the vehicle cools down for 6 to 30 hours.
In practice, the preconditioning test is often performed on the day prior to the emission test and vehicle conditioning takes place during the night prior to the type-approval test.

2.6 Limit values of the type-approval test on a dynamometer

The European legislation of road vehicles set out in the directives EC 715/2007 and EC 692/2008 stipulates, among other things, limit values for CO, THC, NO_x, PM and, as of Euro-5b, PN emissions in a type-approval test. In Table 2-2, the limit values which apply to the Jeep Grand Cherokee Euro 5a diesel under investigation are shown.

Table 2-2: Limit values for emissions of the Jeep Grand Cherokee Euro 5a diesel

CO	NO_x	THC+NO_x	PM	PN
[mg/km]	[mg/km]	[mg/km]	[mg/km]	[#/km]
500	180	230	5.0	-

The CO_2 emissions are not limited in the aforementioned European directives but are measured and specified for each vehicle type. For the Jeep Grand Cherokee Euro 5 diesel which was tested, the specified CO_2 emissions in the NEDC test cycle are 218 g/km.

2.7 Other test cycles

In addition to the NEDC tests, this study also conducted other emission tests:

- Tests with constant driving speeds (50, 80, 100 and 120 km/h).
- UDC tests, see Figure 2-5.

The first 780 seconds of the NEDC test cycle has a speed pattern of up to 50 km/h. This part of the NEDC (see Figure 2-2) is referred to as the UDC test (Urban Driving Cycle). The UDC test consists of four equal parts (four ECE test cycles with a duration of 195 seconds). By repeating these ECE tests, a picture of the emission behaviour over time can be obtained.
The UDC test was repeated four times during the conducted tests and in this case consists of 16 ECE cycles with a total duration of 3120 seconds.

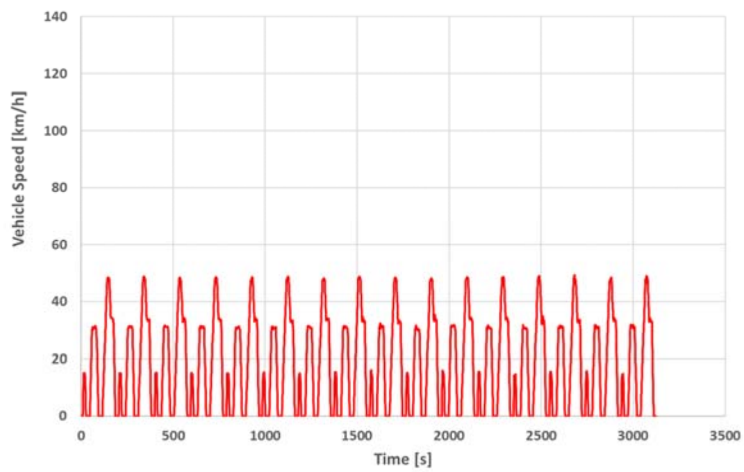

Figure 2-5: 4*UDC test cycles, 16 kilometres in total

2.8 Road tests, measuring equipment and emissions in practice

In recent decades, it has become apparent that practical emissions on the road can be much higher than emissions measured in the laboratory. This particularly applies to CO_2 and NO_x emissions. In 2017, this led to new legislation that also requires road emissions testing. The vehicle is then equipped with special mobile measuring equipment, also called the Portable Emission Measurement System (PEMS).
This test cycle is called a Real Driving Emission (RDE) test. An RDE test takes 90-120 minutes and is performed in the city, on country roads and on motorways.

PEMS measuring equipment has various exhaust gas analysers and their operation is very complex and time-consuming. TNO has developed a simpler measurement system, called the Smart Emission Measurement System (SEMS). This system is based on a combination of existing sensors and our internally developed data logger. The SEMS system has been used by TNO for many years for many emission measurements and has also been used in this project.

The quality of the tests with mobile measuring equipment on the road is less than that of dynamometer measurements, but can be used effectively, particularly in combination with validation on a dynamometer. This is also regularly checked for SEMS in correlation experiments, in which SEMS is used together with certified laboratory equipment. A mobile measurement setup makes it possible to measure practical emissions.

In comparison with dynamometer tests, the emissions measured during road tests can vary more strongly, due to the following elements, among other things:

- Variations in conditions on the road, the most important of which are the type of road surface, the slope of the road, the bend radius, the wind force and direction, the outside temperature, the air humidity and any precipitation.
- Additionally, driving conditions may vary considerably in practice, such as vehicle load, use of the vehicle (air conditioning, use of electrical components, open or closed windows), driving style (calm versus sporty), speed and traffic conditions.

Therefore, emission tests on the road are not significantly worse than dynamometer tests, but differ from dynamometer tests and have more variation.

3 Test vehicle data and research locations

3.1 Vehicle data

The details of the tested Jeep Grand Cherokee are shown in Table 3-1. Some engine details are shown in Appendix E. The vehicle has been maintained during its lifetime in accordance with the manufacturer's instructions.
Since, during the test programme, the test vehicle has passed the age limit of 5 years, the vehicle is no longer required to meet the In-Service-Conformity demands, as of January 2018. The vehicle mileage is lower than 100,000 km. During the dynamometer programme, FCA performed the software update of the engine calibration in the presence of TNO and RDW, after which a second set of tests were carried out.

Table 3-1: Jeep Grand Cherokee data

Make	[-]	Jeep
Type	[-]	Grand Cherokee CRD
Class	[-]	Passenger vehicle
Vehicle class	[-]	M1G
Fuel	[-]	Diesel
Vehicle Identification Number (VIN)	[-]	1C4RJFBM3CC339555
Engine displacement	[cm^3]	2,987
Max. Power	[kW]	177
Gear box		Automatic transmission.
Emission class	[-]	Euro 5a
Type-approval authority	[-]	e4*2007/46 * 0186*06
Type-approval guideline	[-]	715/2007*692/2008A
Vehicle weight empty	[kg]	2,247
Mileage	[km]	82,659
Date of first registration	[dd-mm-yy]	17-01-13
Engine calibration 1, before update		68079778AJ
Verification number of calibration 1		E65EEFED
Engine calibration 2, after update		68079778AM
Verification number of calibration 2		D1ECC1B4

3.2 Measuring equipment

3.2.1 Dynamometer

The dynamometer at Horiba Europe GmbH was used and meets the legal requirements for type-approval and is certified according to ISO 17025.
The dynamometer consists of two rollers on which the front and rear axles of the vehicle are placed. In order to measure emissions, we use a dilution tunnel with Constant Volume Sampler (CVS), sampling bags, and exhaust gas analysers that analyse both diluted and undiluted exhaust gas. The detailed specifications of the dynamometer are provided in Appendix D.

Figure 3-1: Dynamometer with measurement equipment for performing an emissions test

3.2.2 Mobile measuring system SEMS

The measurements that were conducted on and near the RDW test track in Lelystad were performed with the SEMS. Figure 3-2 shows the schematic of the connection of SEMS to the engine of the Jeep Grand Cherokee.

SEMS test results are based on calibrated NO_x-O_2 sensors installed in the exhaust system as well as vehicle data taken from the OBD system. Position data of the test vehicle is also determined via a GPS receiver, which is part of the SEMS. After the test data is stored in a database via a mobile data connection, corrections, signal alignment and calculations take place. This SEMS measurement system has been validated in the test programme on the dynamometer.

An important part of the NO_x reduction is the application of EGR (Exhaust Gas Recirculation) in the engine where part of the exhaust gas is recycled to the cylinder. To gain insight into the operation of the EGR, the position signal (analogue DC voltage) from the EGR valve was read into the SEMS with the aid of an Analog-Digital-Converter (ADC). Additionally, engine signals have been logged which provide insight into the operation of the EGR system.

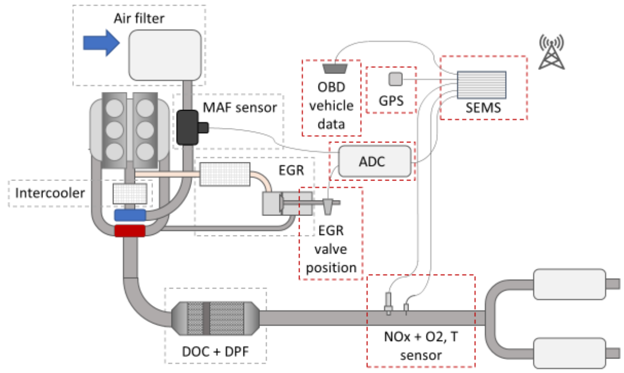

Figure 3-2: Schematic representation of the engine of the Jeep Grand Cherokee and the TNO Smart Emission Measurement System (SEMS)

In the above figure, the bypass valve of the intercooler is not shown. The intercooler is switched off during the regeneration of the soot filter, because a high exhaust gas temperature in the soot filter is required for this.

3.3 Testing locations

3.3.1 Dynamometer

For this project, we used the dynamometer from Horiba Europe GmbH, located in Oberursel (Taunus) in Germany. A truck was used to transport the test vehicle to Horiba.

3.3.2 Test Centre Lelystad (TCL)

The first exploratory emissions tests were conducted on the test track of the RDW in Lelystad, see Figure 3-3. This has a length of 2.8 kilometres, consisting of 1.4 km of straight track and 1.4 km of (bowl) turns.

Figure 3-3: RDW test track Lelystad (TCL)

3.3.3 *RDE route Lelystad*

The RDW has developed an RDE route in the Lelystad area. This has a length of 87 kilometres and includes a city road section, an outer road section and a motorway section.

Figure 3-4: 3RDE route Lelystad

3.4 Test cycles

In this study, tests were conducted with the following test cycles:

- NEDC test starting with a cold engine, see section 2.3
- NEDC test starting with a warm engine, see section 2.3
- EUDC test starting with a warm engine, see section 2.5
- Constant speeds (50, 80, 100 and 120 km/h).
- UDC test starting with a cold engine, see section 2.7
- UDC test starting with a warm engine, see section 2.7
- RDE test, see section 3.3.3

Table 3-2 provides an overview of the parameters of the test cycles used.

Table 3-2: Overview of test cycles

Test	Distance [km]	Duration [s]	Average Speed [km/h]
NEDC	11.0	1180	33.6
3*EUDC	20.8	1200	62.4
4*UDC	16.3	3120	18.7
ECE	1.0	195	18.7
RDE Lelystad	83.0	5617*	55.9

* Indication. The duration of an RDE test depends on the current traffic conditions.

In order to carry out the tests on the test track in Lelystad, the RDW has installed a so-called "driver aid" in the test vehicle. The driver aid instructs the driver on the speed profile to be followed and the circuit diagram of a manual gearbox.

3.5 Fuels

The reference fuel CEC-RF-06-08 B5 is used in the dynamometer programme, the certificates of which are included in Appendix A.

The emissions tests on the test track in Lelystad were performed with commercial fuel with EN590 specification.

4 Results

The results of the emissions study are presented thematically in this chapter with the aim of increasing the readability of this report.
This means that the results of the tests that were conducted at different times, are compared to each other. In some cases the results of previously conducted exploratory RDW emission studies are also included.

4.1 Determination of the driving resistance of the test vehicle on the test track

In this section, partial objective 2 of section 1.2 is discussed.

Background:
The emission tests that were conducted on the test track in this project, were partially repeated on the dynamometer. When testing on the dynamometer, the driving resistance curve of the test vehicle needs to be set. If the driving resistance curve determined on the test track is set on the dynamometer, the test conditions on the dynamometer are able to approximate the situation on the test track. See also section 2.4 for more background information on the determination of the driving resistance curve.

The driving resistance curve has also been determined by the manufacturer prior to the type-approval test, this is indicated in Figure 4-2 and Table 4-1 by “OEM” or “RL 1”.

Execution:
In this study, the driving resistance curve of the test vehicle was determined in accordance with the legal procedure. This test is first carried out on the straight sections of the test track and is indicated by "TCL" in the results, see Figure 4-2.
At the end of the test programme, the driving resistance curve of the test vehicle over the entire test track is determined (including the bends), see Figure 4-1.
In this case, all measurement data are fitted using the least squares method on the second order driving resistance curve. The test track in Lelystad consists of two straight sections and two turns, see section 3.3.2. Sixteen road load tests were performed with six different starting points on the test track. This approach enables a good distribution of the different speeds across the track sections.

Result:
The TLC driving resistance curve is higher than the OEM curve, especially at lower speeds.

Possible causes of this increased driving resistance are:
- A road surface with more driving resistance;
- A high vehicle weight;
- More friction in the powertrain of the test vehicle than in the vehicle used for the type-approval;
- Tires with a higher rolling resistance.

The results of these driving resistance curves (in red and green) are shown in Figure 4-2 and Table 4-1. Through curved turns, the average driving resistance on the test track in Lelystad increases over the speed interval of 10-130 km/h by approximately 400 N. This means the driving resistance doubles at lower speeds.

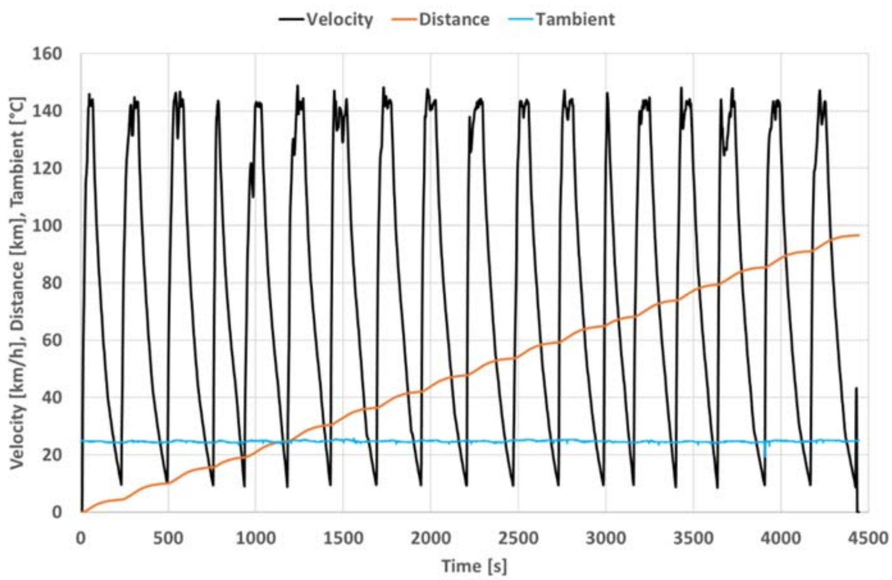

Figure 4-1: Road load testing of the Jeep Grand Cherokee on the test track in Lelystad with six different starting points on the test track

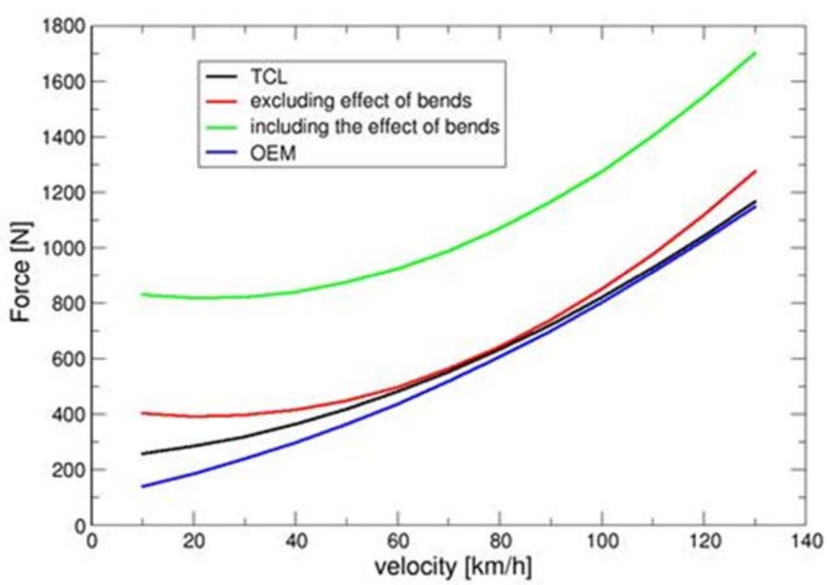

Figure 4-2: Driving resistance curves of the Jeep Grand Cherokee under different conditions

Table 4-1: Coefficients of the driving resistance curves of the Jeep Grand Cherokee

Source	Inertia	F0	F1	F2
	[kg]	[N]	[N/km]	[N/km^2]
OEM (RL1) blue	2270	102.5	3.50	0.0350
TCL (RL 2) black	2517	239.2	1.38	0.0443
TCL (RL 3) red	2491	432.3	-3.49	0.0768
TCL (RL 4) green	2491	857.3	-3.49	0.0768

Partial conclusion 1:
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 0.5 to 1.0 times higher than the driving resistance curve determined by the manufacturer. The absolute difference in driving resistance is constant over the speed range of 10-130 km/h and is about 600-700 N. This difference is largely caused by the turns of the test track.

4.2 Study emissions on a test track and on public roads

4.2.1 Measured emissions in practice before the software update

This section discusses partial objective 4 from section 1.2.

Background:
In the exploratory RDW study from 2017, various emissions tests were conducted on a first Jeep Grand Cherokee on the test track at an ambient temperature of 16 to 25 °C. The measured NO_x emissions ranged from 970 to 2195 mg/km.
In two RDE tests, which provide a good estimation of daily emissions in practice, an NO_x emission of 1672 and 1889 mg/km was measured, also see section 1.1.

Execution:
This emissions study was conducted on a second Jeep Grand Cherokee Euro 5a diesel. First, a number of tests that were performed on the first vehicle in the exploratory emissions study were repeated [RDW 2017].

Result:
The exploratory emissions tests were conducted at an ambient temperature of 5 to 14 °C. The measured NO_x emissions Figure 4-3ranged from 1689 to 3857 mg/km, see Figure 4-3. This figure also specifies which test cycles were run during these tests. In the two RDE tests, an NO_x emission of respectively 1847 and 2171 mg/km was measured.

Partial conclusion 2:
Two Jeep Grand Cherokee Euro 5 diesel vehicles with the original engine calibration C1 were tested. The first was tested in the RDW study of 2017 and the second was tested in this study. In both cases, the emission tests on the test track showed that the vehicles significantly exceed the NO_x limit value of 180 mg/km and have similar emission behaviour.

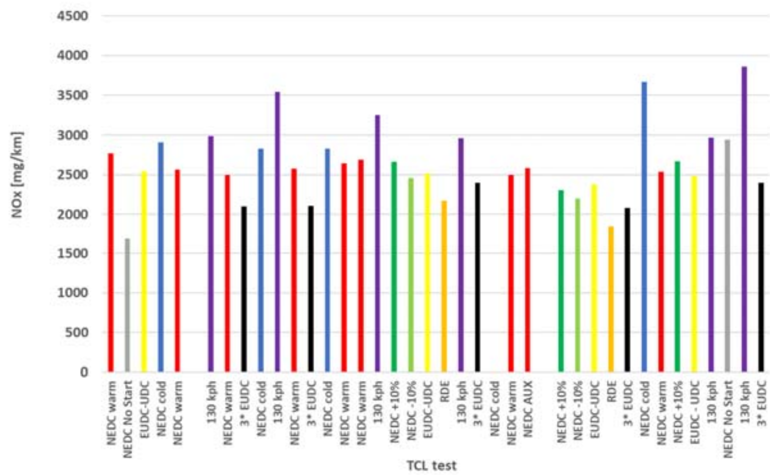

Figure 4-3: NO_x emissions from the first exploratory test track measurements of the investigated Jeep Grand Cherokee Euro 5 diesel with engine calibration C1

4.2.2 *Effects of ambient temperature on emissions*

This section discusses partial objective 9 of section 1.2 and the following research question in particular: To what extent does the ambient temperature influence the emission behaviour of the test vehicle?

Background:
In Europe, the outside temperatures can vary considerably during the calendar year. Since the outside temperature is measured by the vehicle, the question is to what extent this affects the engine adjustment.

Execution:
To answer this question, NEDC tests with a cold start were performed on different days with different ambient temperatures.

Result:
In Table 4-2 and Figure 4-4, the emission results are presented.
In the tests carried out by the RDW on the first vehicle in 2016, the ambient temperature was 14 - 21 °C, for the second vehicle tested in 2018, the ambient temperature was 2 - 10 °C.

Table 4-2: NEDC test results on the test track with two test vehicles with engine calibration 1 at different ambient temperatures

Date	Ambient temperature [°C]	CO_2 [g/km]	NO_x [mg/km]
31-05-2016	21	282.5	983
02-06-2016	18	292.5	1152
03-06-2016	13	291.8	1283
06-06-2016	14	280.7	1249
14-03-2018	8	316.7	2908
15-03-2018	9	319.6	2832
16-03-2018	10	325.9	2833
21-03-2018	2	358.0	3670

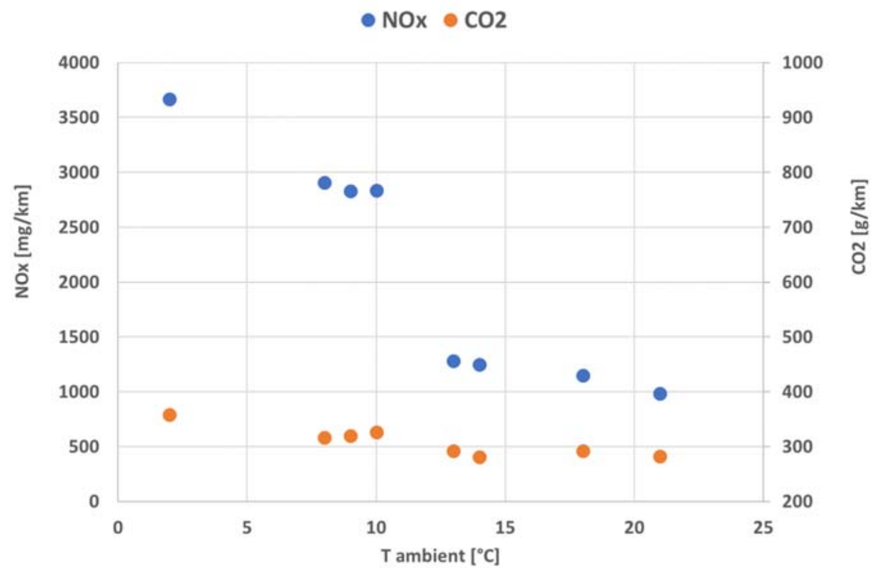

Figure 4-4: NO_x and CO_2 emissions measured on the test track with engine calibration 1 at different ambient temperatures

Partial conclusion 3:
Based on NEDC testing with a cold start of the Jeep Grand Cherokee Euro 5 diesel with the original engine calibration C1, which was performed on the test track in different ambient temperatures, it appears that the NO_x emission rises from approx. 1000 to more than 3500 mg/km if the ambient temperature drops from 21 to 2 °C. The corresponding CO_2 emission rises from 281 to 358 g/km. This shows that the NO_x and CO_2 emissions from the Jeep Grand Cherokee Euro 5 diesel with the original engine calibration are strongly dependent on the ambient temperature.

4.2.3 Effects on emissions when starting with a cold and warm engine

This section discusses sub-objectives 5 and 9 of section 1.2, and the following research questions in particular: To what extent does the thermal condition or coolant temperature when the engine is started affect the emission behaviour of the vehicle? How does the EGR system behave when the NO_x emissions of the engine vary?

Background:
The effect of an engine's starting thermal condition on vehicle emissions can be mapped by starting identical tests with different coolant temperatures, a so-called "cold" and "warm" engine or cold and hot start. Tests with a cold start, begin with a coolant temperature of 25 °C or the current ambient temperature and tests with a hot start begin with a coolant temperature of 80-85 °C.
The behaviour of the EGR system has been further investigated by measuring the position signal of the EGR valve. This position signal is a direct voltage and is expressed in millivolts (mV). The EGR valve is closed with a low DC voltage and is open with a high DC voltage.

Execution:
In this test programme, NEDC tests with cold and hot starts were carried out one after the other, both on the test track and on the dynamometer.

Result:
The NO_x emissions from NEDC tests with cold and hot starts are shown in Table 4-3. In ambient temperatures below 14 °C, the NO_x emissions are high (2538 – 3670 mg/km) in tests with a cold and hot start.
With ambient temperatures between 20 and 24 °C, the NO_x emission in the NEDC test with a cold start decrease significantly (up to 970 - 1319 mg/km on the test track and up to 199 - 220 mg/km on the dynamometer). The NO_x emissions in an NEDC test with a hot start are 1874 – 2195 mg/km on the test track and 1630 and 1498 mg/km on the dynamometer.

Table 4-3: NO_x and CO_2 emissions of NEDC tests with cold and hot starts on the dynamometer and test track with engine calibration 1

Date	**T environment [°C]**	**CO_2 [g/km]**	**NO_x [mg/km]**	**CO_2 [g/km]**	**NO_x [mg/km]**	**Location**
	Cold and hot start	**Cold start**		**Hot start**		
31-05-2016	20 and 20	283	970	254	1874	Test track
03-06-2016	17 and 17	292	1283	258	1935	Test track
05-08-2016	25 and 25	236	220	216	1630	Dynamometer
14-03-2018	8 and 14	317	2908	309	2568	Test track
15-03-2018	9 and 9	320	2832	299	2581	Test track
16-03-2018	10 and 8	326	2833	306	2644	Test track
21-03-2018	2 and 2	358	3670	286	2538	Test track
22-05-2018	24 and 24	309	1319	283	2195	Test track
15-08-2018	23 and 23	242	199	214	1498	Dynamometer

The cause of the large differences in NO_x emissions in the NEDC tests with a cold and hot start have been investigated further. In Figure 4-5 - Figure 4-7, the graphs of NEDC tests are shown with the NEDC speed profile (VSS), the coolant temperature (ECT), the temperature in the engine inlet (IAT), the ambient temperature (Tambient), the position signal of the EGR valve and the NO_x emissions.

In the NEDC test with a cold start resulting in an NO_x emission of 1319 mg/km, the temperature in the inlet (IAT) of the engine drops after 750 seconds from around 70 to 30 °C. The EGR valve is partially closed at that time (see Figure 4-6) and, at the same time, the NO_x emission rises substantially, see Figure 4-5. The decline of IAT takes place after 750 seconds and this is possibly caused by the (partial) shutdown of the EGR system.

With the EGR system switched on, relatively hot (>80 °C) exhaust gas is mixed with the inlet air of the engine. The temperature of the inlet air of the engine (IAT) rises under these conditions and the NO_x emissions decline.

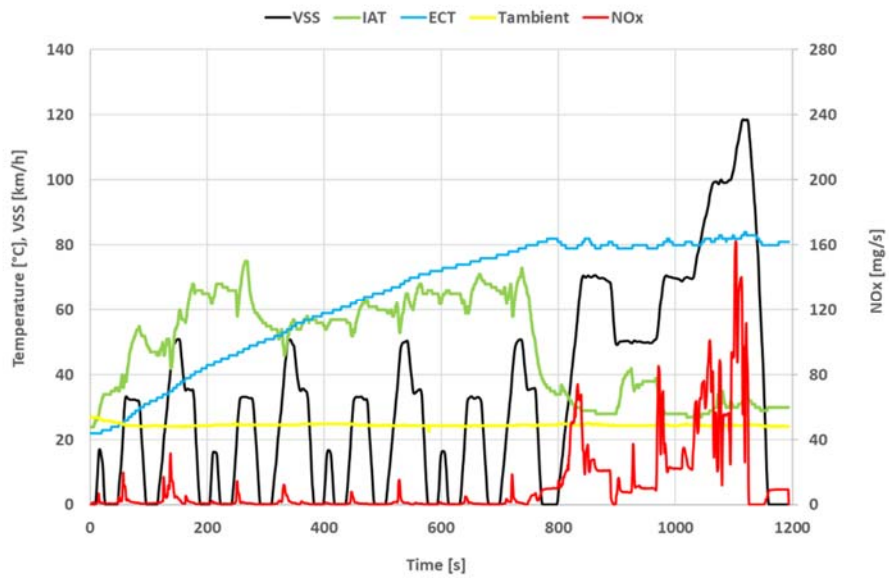

Figure 4-5: NEDC test with engine calibration 1 and cold start on 22-05-2018 on the test track. After 750 seconds, the temperature in the engine inlet (IAT) drops and the NO_x emissions rise substantially.

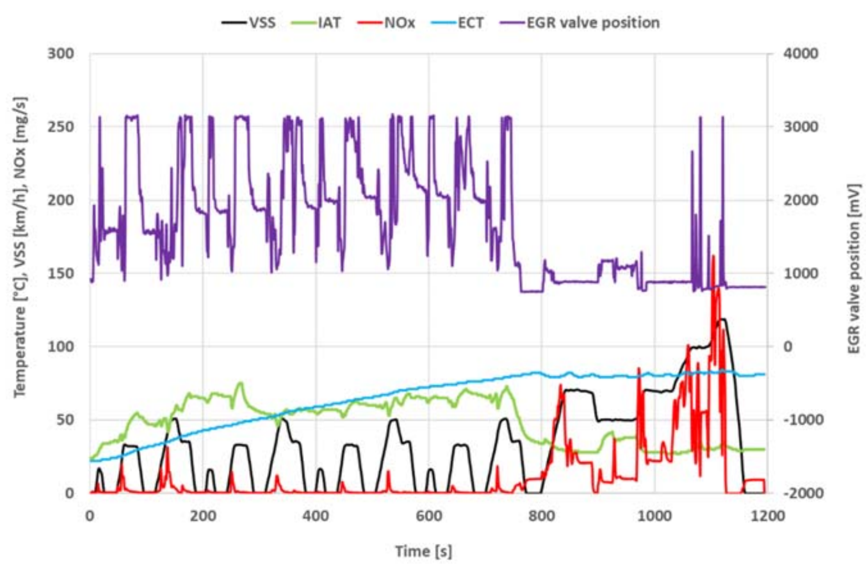

Figure 4-6: NEDC test with engine calibration 1 and cold start on 22-05-2018 on the test track. After 750 seconds, the temperature in the engine inlet (IAT) drops and the NO_x emissions rise substantially. This is possibly caused by the (partial) shutdown of the EGR system. The position signal of the EGR valve varies between 1000 and 3000 mV during the first 750 seconds. After 750 seconds, The EGR valve shows a relatively stable position signal (usually <1000 mV).

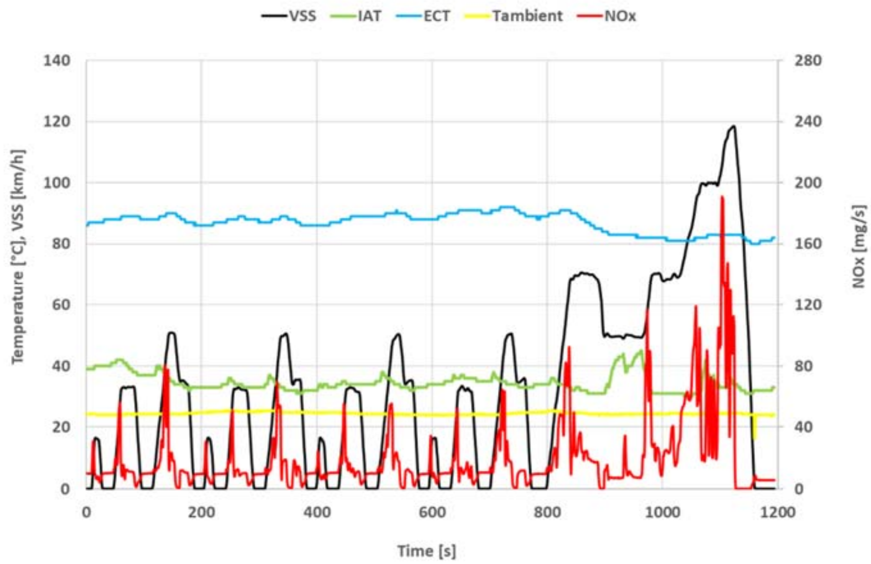

Figure 4-7: NEDC test with engine calibration 1 and cold start on 22-05-2018 on the test track. The temperature in the engine inlet (IAT) is 30 - 45 °C and relatively constant. The NO_x emissions are substantially higher in the first 780 seconds in comparison to the NEDC cold start test. This is possibly caused by the (partial) shutdown of the EGR system.

In the NEDC test with a hot start and an NO_x emission of 2195 mg/km, the temperature of the intake air (IAT) is relatively constant and low at 30-45 °C, see Figure 4-7. The NO_x emissions are substantially higher in the first 780 seconds than in the cold start test. This is caused by a (partial) shutdown of the EGR system that is controlled by the engine management system.

NO_x emissions from a diesel engine with EGR technology are dependent on many parameters. Fuel injection is also an important parameter in addition to the compression ratio of the engine, the inlet temperature, and the amount and the temperature of the recycled exhaust gas. This particularly concerns the fuel injection pressure, the amount of injections per combustion cycle, and the time of the fuel injections.

Partial conclusion 4:
In NEDC tests with engine calibration 1 and a hot start on the test track, the NO_x emissions are up to a factor of two (2) as high as in an NEDC test on the test track with a cold start (1874 versus 970 mg/km). On the dynamometer, the emissions are almost eight times higher (1498 versus 199 mg/km). Therefore, different NO_x emissions are measured in NEDC testing with a cold start compared to a hot start and different NO_x emissions are measured on the dynamometer compared to the test track. All these differences can be primarily attributed to the different amounts of exhaust gas that flow back to the engine (EGR), caused by the active control of the EGR valve by the operating system of the engine. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.

4.2.4 *Emission behaviour curve after the engine has started*

This section discusses sub-objectives 5, 6 and 10 of section 1.2, and the following research question in particular: To what extent does the emission behaviour of the vehicle change after the engine has started?

Background:
It is generally known that an engine warms up after a cold start and that the emission behaviour of the vehicle changes during this warm-up phase. In the research reference [RDW 2017] carried out previously by the RDW, questions arose that relate to the active switching on or off of systems over time, distance travelled or cumulated parameters after the engine has been started. In principle, these questions are not connected to the warming up of an engine, but may also play a role at the same time. Special attention has been paid to the behaviour of the EGR system and for this, just like in section 4.2.3, the position signal of the EGR valve has been measured.

Execution:
The heating behaviour of an engine has been investigated with a test cycle that does not vary (constant speed) or is repeated (ECE cycles). UDC tests, such as those described in section 2.7, were used in this study amongst others. The ECE test cycle lasts for 195 seconds and is repeated sixteen times. This test is further referred to as 4*UDC test.

On the test track in Lelystad, seven 4*UDC tests with a cold start, six 4*UDC tests with a hot start and tests at constant speeds were carried out with engine calibration C1. The NO_x emission in mg was calculated for each ECE cycle and is presented as bar graphs in Figure 4-8, as well as Figure 4-23, Figure 4-17 and Figure 4-22. Tests have also been conducted at constant speeds, see Figure 4-15 and Figure 4-16.

To verify the emission tests on the test track, 4*UDC cold start tests were conducted on the dynamometer with engine calibration C1. The results are shown in Figure 4-18 to Figure 4-21.

Result:
The 4*UDC tests with a cold start (see Figure 4-8 to Figure 4-23), show that there are two NO_x levels, namely less than 500 mg and more than 2000 mg per ECE cycle. During a 4*UDC test, the NO_x emission suddenly jumps from a low to a high level in almost all cases, but this does not take place at fixed times. The time of the NO_x emission jump varies from 120 to approximately 1450 seconds after the cold start. These 4*UDC tests were performed at ambient temperatures of 10 to 27 °C. In Figure 4-10, the NO_x emission, the air consumption and average ECT, IAT and position signal of the EGR valve of a 4*UDC test are shown for each ECE cycle. In the eighth ECE cycle, the IAT and the position signal of the EGR valve decrease and the NO_x emission and the air consumption increase per ECE cycle.

From the 4*UDC tests with a warm start (see Figure 4-22), it appears that the NO_x emissions in the ECE cycles are 2700-3000 mg. There is no jump in NO_x emissions and the EGR regulation appears to be stable.

The tests at constant speeds (50 and 100 km/h) (see Figure 4-15 and Figure 4-16), provide a different picture. At 50 km/h, starting with a cold engine and reaching a coolant temperature of 80 °C after a distance of 10 km, the NO_x emissions jump from 2 to 11-17 mg/s.

At 100 km/h, the NO_x emissions vary while the engine is warming up. Once heated up, the NO_x emission fluctuates between 10 and 50 mg/s. This appears to relate to the driving direction of the vehicle on the test track. The cycle of the intake air (IAT) lasts for 100 seconds and at a speed of 100 km/h this corresponds to the length of the test track of 2.8 kilometres. The effectiveness of the EGR and/or intake air cooling is likely to increase or decrease as a result of the wind direction.

Analysis:
On the test track, it was not possible to reproduce the time of the NO_x jump in the 4*UDC test. The following elements may play a role: The 3*EUDC preconditioning test, which is conducted prior to every 4*UDC cold start test, ends on the test track after which the test vehicle is driven to the conditioning room. This last stretch to the conditioning space is undefined, both in terms of speed and distance. The various ambient temperatures at which the emission tests were conducted may also play a role.

Changes in the temperature of the inlet (IAT) appear to be directly related to the position signal of the EGR valve. If the EGR valve (partially) closes, IAT decreases and the MAF increases. This means that the measured changes of the IAT are due to the increased or decreased supply of EGR to the intake air. Of course it also works the other way around, opening the EGR valve causes the IAT to rise.

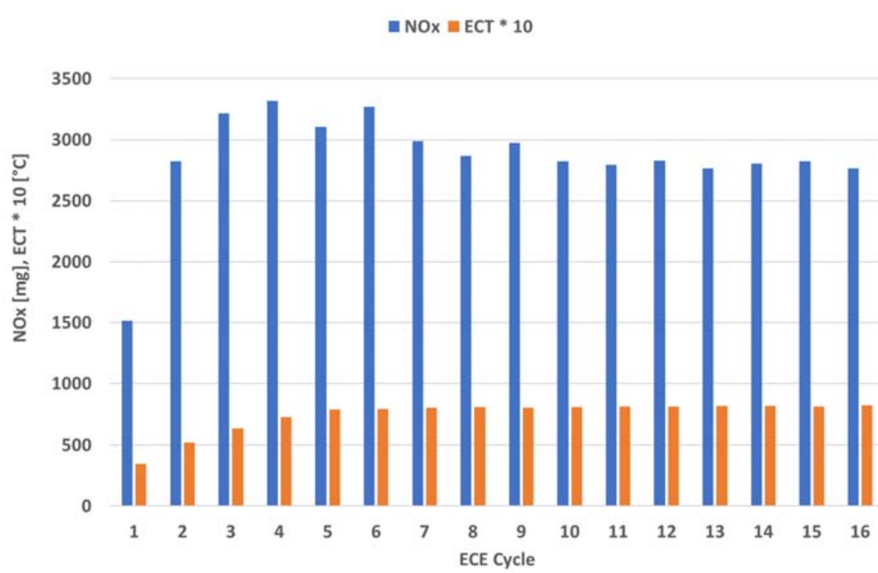

Figure 4-8: NO_x emissions per ECE cycle of a 1*UDC test with engine calibration C1 and a cold start, performed on 28-03-2018. The test started in a conditioning room of 26 °C and was conducted on the test track of the RDW with an ambient temperature of 10 °C. Preconditioning 3*EUDC with hot start.

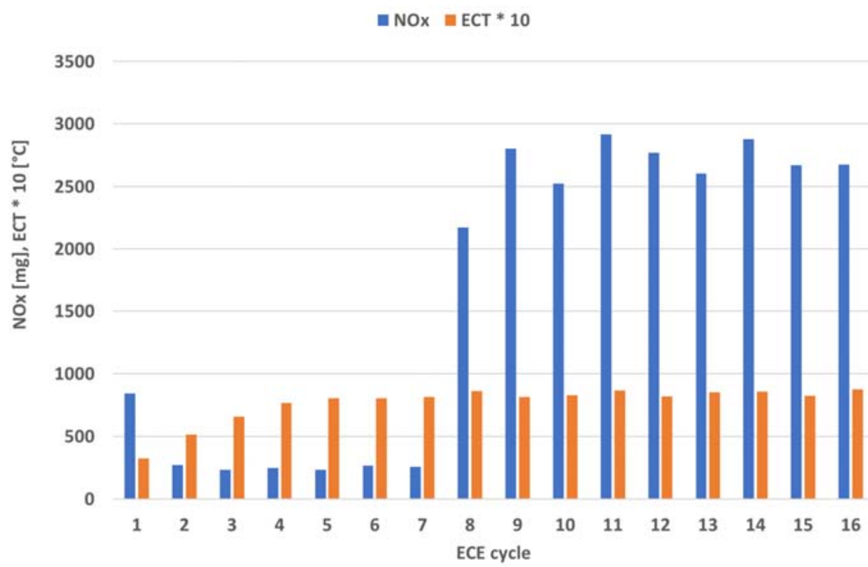

Figure 4-9: NO_x emissions per ECE cycle of a 4*UDC test with engine calibration C1 and a cold start, performed on 03-04-2018. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 18-20 °C. Preconditioning 3*EUDC with hot start.

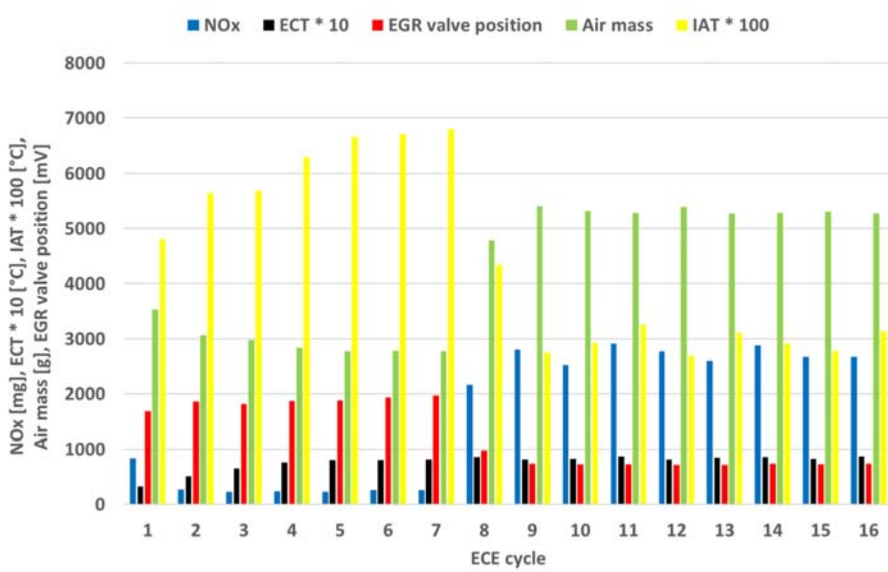

Figure 4-10: NO_x emission, air consumption and average ECT, IAT and position signal of the EGR valve per ECE cycle of a 4*UDC test with engine calibration C1 and cold start, performed on 03-04-2018. The test started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 18-20 °C. Preconditioning 3*EUDC with hot start.

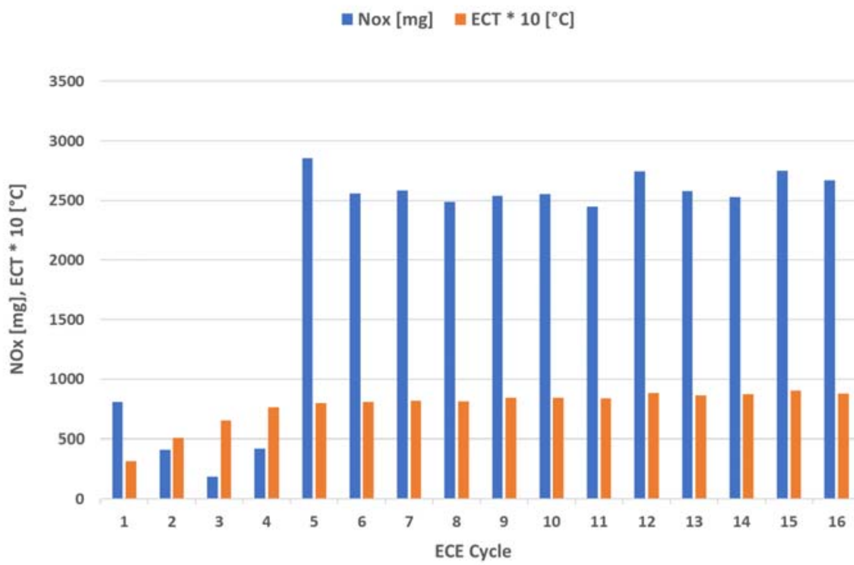

Figure 4-11: NO_x emissions per ECE cycle of a 4*UDC test with engine calibration C1 and cold start, performed on 09-04-2018. The test started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 20 °C. Preconditioning 3*EUDC with hot start.

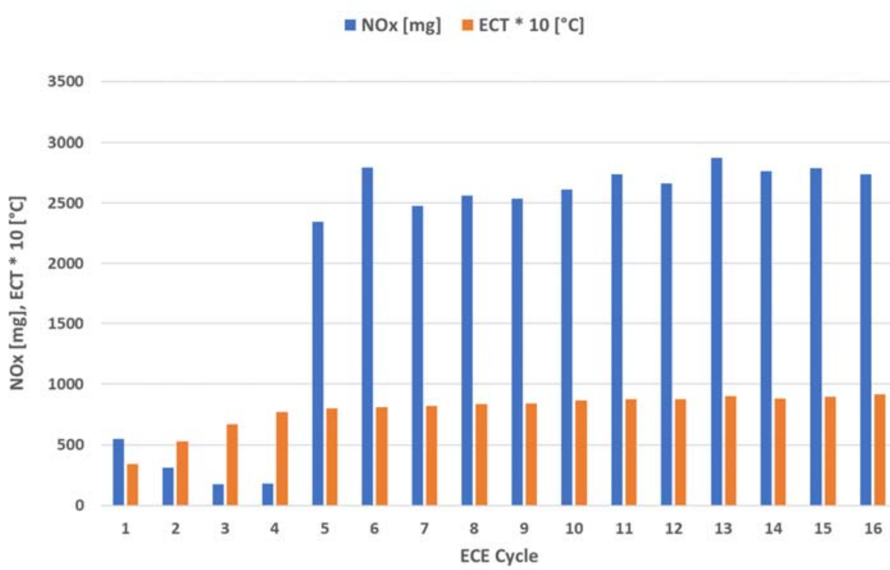

Figure 4-12: NO_x emissions per ECE cycle of a 4*UDC test with engine calibration C1 and cold start, performed on 19-04-2018. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 27 °C. Preconditioning 3*EUDC with hot start.

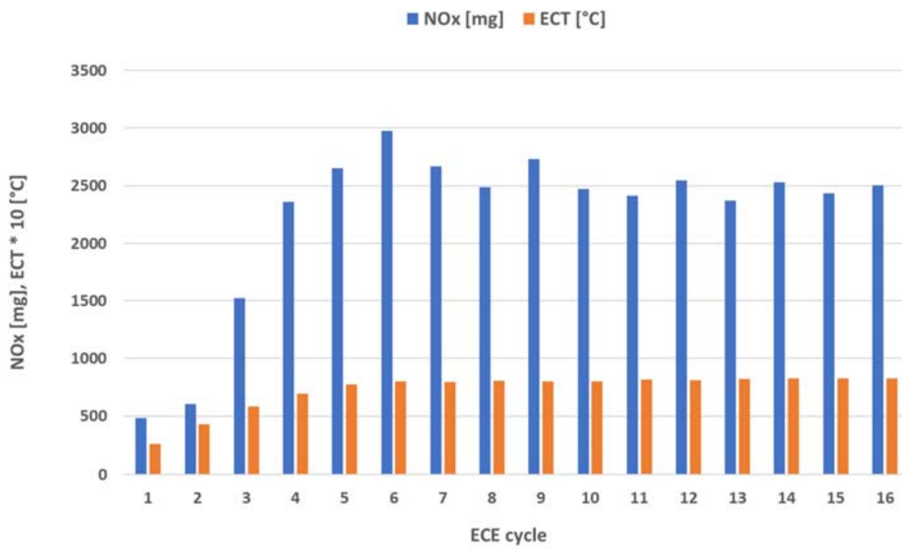

Figure 4-13: NO_x emissions per ECE cycle of a 4*UDC test with engine calibration C1 and cold start, performed on 24-04-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW with an ambient temperature of 14 °C. Preconditioning 3*EUDC with hot start.

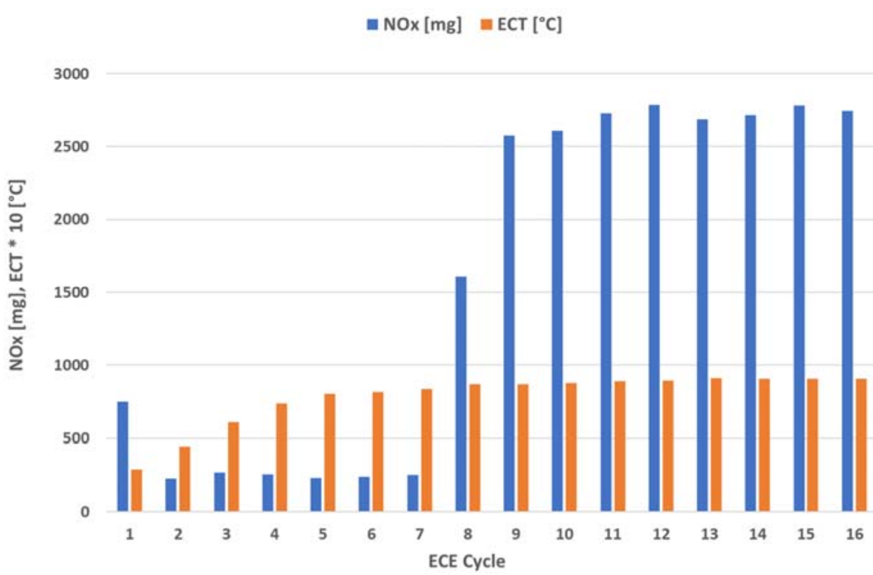

Figure 4-14: NO_x emissions per ECE cycle of a 4*UDC test with engine calibration C1 and cold start, performed on 08-05-2018. The test was started in a conditioning room of 27 °C and was conducted on the test track of the RDW with an ambient temperature of 27 °C. Preconditioning 3*EUDC with hot start.

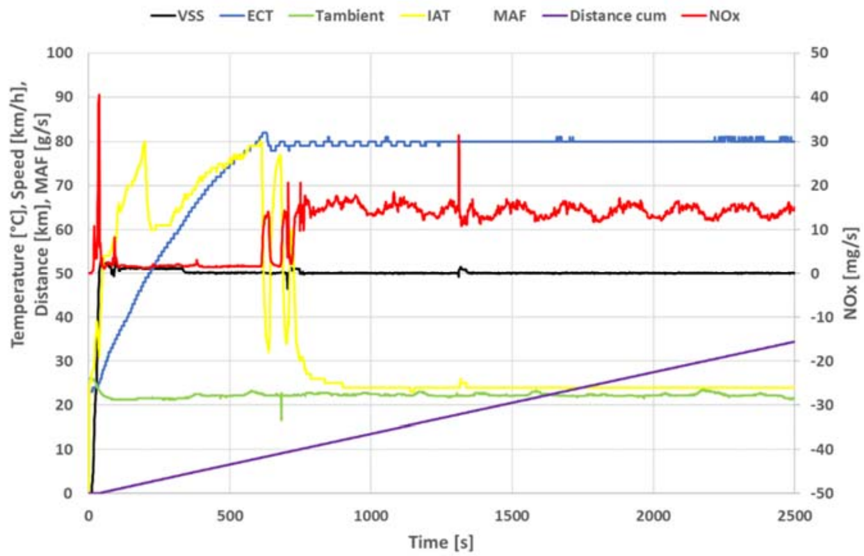

Figure 4-15: NO_x emissions during a cold start with engine calibration C1 and a constant speed of 50 km/h. During the period in which the coolant temperature is rising (ECT is 20 - 80 °C), the NO_x emissions are less than 2 mg/s. The NO_x emission of the warmed up engine (ECT is 80 °C) is 11 – 17 mg/s.

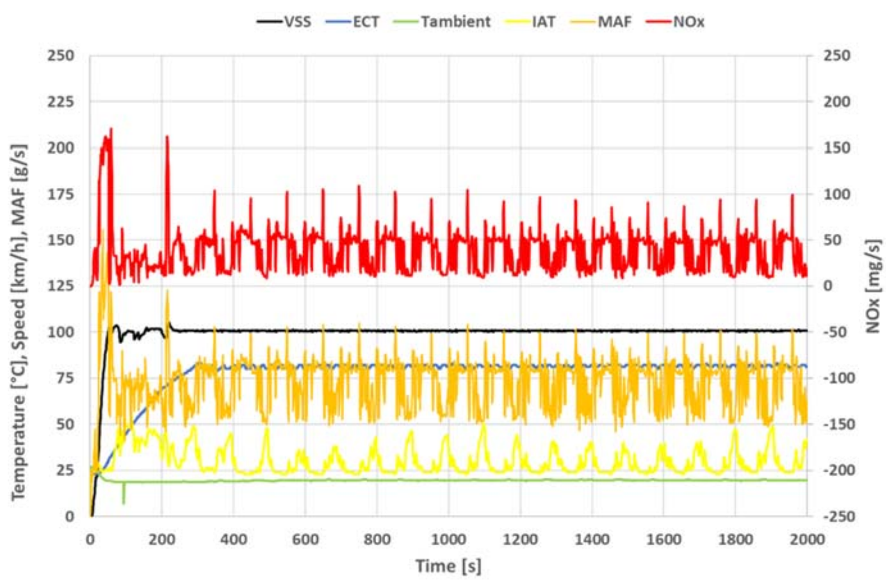

Figure 4-16: NO_x emissions during a cold start with engine calibration 1 and a constant speed of 100 km/h. During the period in which the coolant temperature is rising (ECT is 20 - 80 °C), the NO_x emission varies. The NO_x emission of a warmed up engine (ECT is 80 °C) fluctuates between 10 and 50 mg/s.

What changes in engine conditions occur during the jump in NO_x emission?
In Figure 4-17, a few parameters of the 4*UDC test of 19-04-2018 are shown. At t = 800 seconds, when leaving the NEDC speed curve, the intake air temperature of the engine (IAT) appears to fall from 70 to 35 °C and the NO_x emission increases substantially. This corresponds to the NO_x emission trend shown in Figure 4-12. The jump in NO_x emissions in the 4*UDC tests is primarily due to the change in the quantity of EGR. Similar emission behaviour has been established in NEDC tests with cold and hot starts, see Table 4-3.

The underlying method of controlling the EGR system at various points during the 4*UDC tests with a cold start was not found.

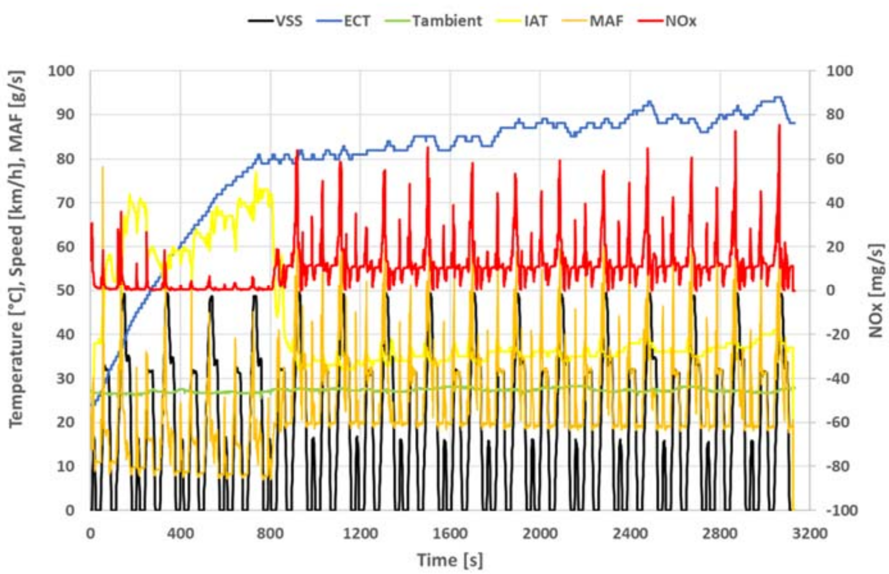

Figure 4-17: Diverse parameters of a 4*UDC test with a cold start and engine calibration C1, performed on 19-04-2018. The test started in a conditioning room of 25 °C and was conducted on the RDW test track with an ambient temperature of 27 °C.

Verification of the emission behaviour on the dynamometer
The trend after a cold start was also measured on the dynamometer in 4*UDC tests with two different running resistance curves (RL1 and RL2), at a constant ambient temperature of 23 °C. The test results are shown in Figure 4-18 to Figure 4-21. Apart from the first test of 16-08-2018, the same NO_x emission trend as on the test track can be seen in the other tests. Over time, the NO_x emissions suddenly increase sharply. During the last three tests, this takes place in the eighth ECE cycle. Only in the first 4*UDC test of 16-08-2018 was there a different NO_x emissions trend, but the final level (around 1800 mg/km) remained the same. This may be due to the deviating preconditioning cycle (NEDC with a hot start instead of 3*EUDC with a hot start).

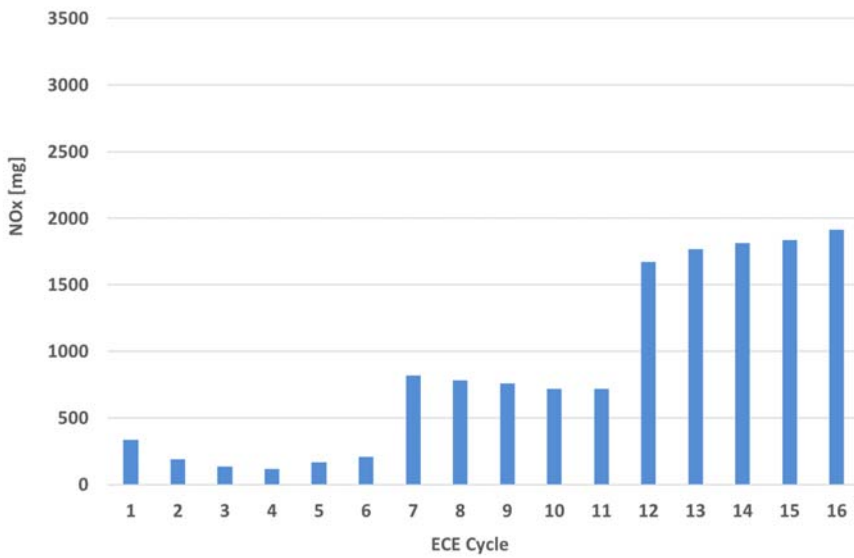

Figure 4-18: NO_x emissions per ECE cycle of a UDC test with a cold start and engine calibration C1, performed on 16-08-2018 on the dynamometer with settings according to manufacturer's specifications (RL1) and an ambient temperature of 23 °C. Preconditioning NEDC with hot start.

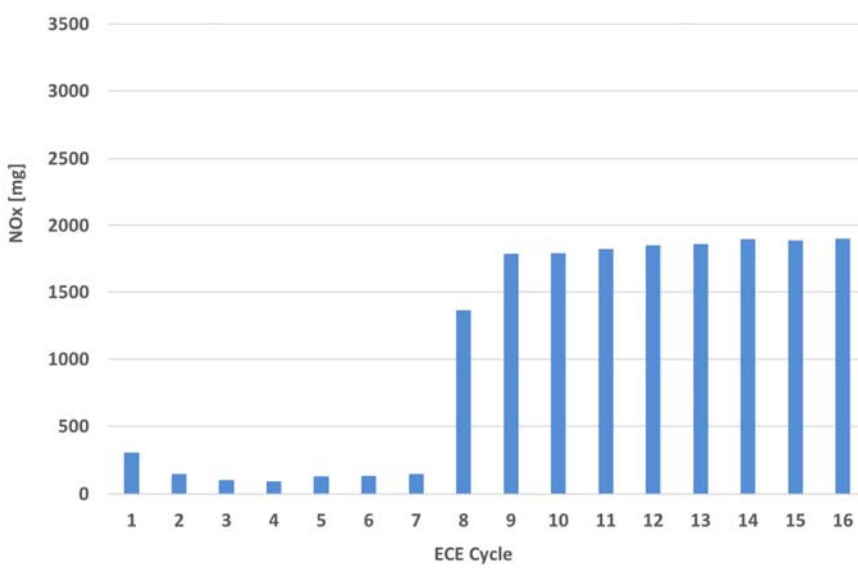

Figure 4-19: NO_x emissions per ECE cycle of a UDC test with cold engine start and engine calibration C1, performed on 23-08-2018 on the dynamometer with settings according to manufacturer's specifications (RL1) and an ambient temperature of 23 °C. Preconditioning 3*EUDC with a hot start.

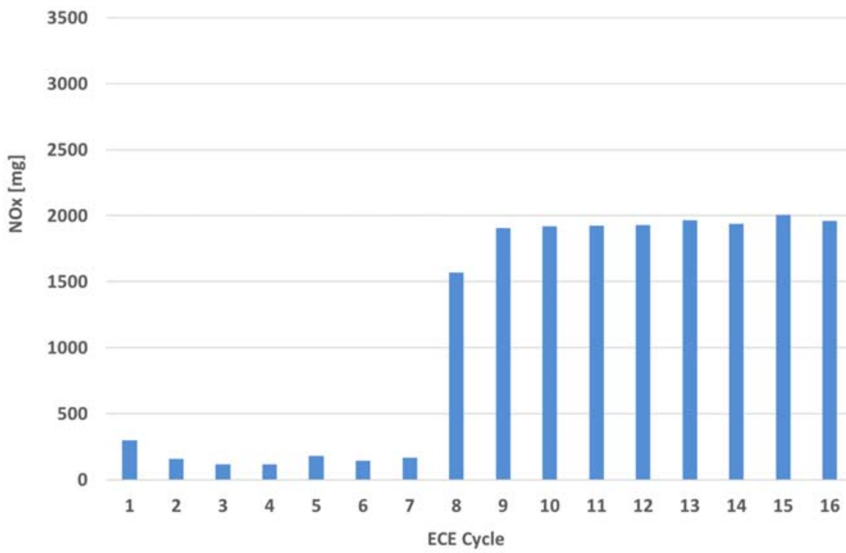

Figure 4-20: NO_x emissions per ECE cycle of a UDC test with cold start and engine calibration C1, performed on 21-08-2018 on the dynamometer with adjusted settings (RL2) and an ambient temperature of 23 °C. Preconditioning 3*EUDC with hot start.

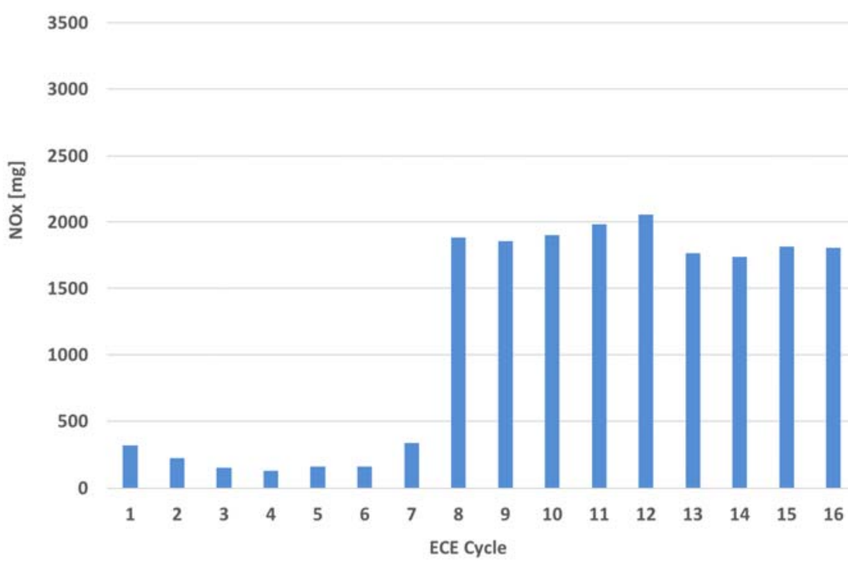

Figure 4-21: NO_x emissions per ECE cycle of a UDC test with cold start and engine calibration C1, performed on 24-08-2018 on the dynamometer with adjusted settings (RL2) and an ambient temperature of 23 °C. Preconditioning 3*EUDC with hot start.

In Figure 4-22 the results of a 4*UDC test on the test track with a hot start are shown. In this test, the NO_x emissions remain at a level between 2682 and 2969 mg per ECE cycle. The EGR system largely seems to be permanently shut down. This can be deduced from the fact that the NO_x emissions in all ECE test cycles are 2650 - 3000 mg.

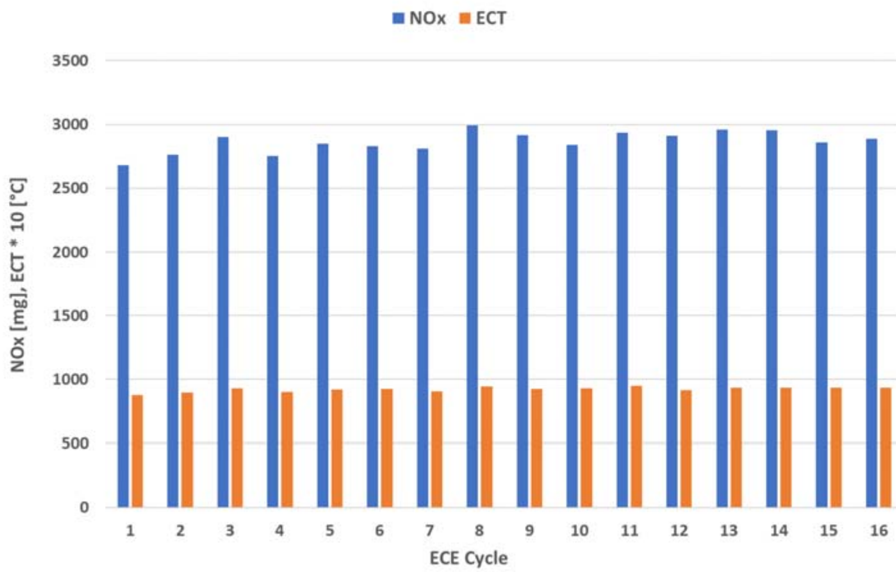

Figure 4-22: NO_x emissions per ECE cycle of a 4*UDC test with cold start and engine calibration C1, performed on 19-04-2018. The test was done on the test track of the RDW with an ambient temperature of 28 - 30 °C. Preconditioning 4*UDC with a cold start.

Partial conclusion 5:
In UDC tests of engine calibration C1 with a cold start, it appears that over time the NO_x emissions abruptly rise from approximately 250 to 1750-2750 mg per ECE cycle. A similar rise in NO_x emissions is measured in the test with a constant speed of 50 km/h. The rise in NO_x emissions is primarily caused by the applied method of controlling the EGR system, which regulates the quantity of EGR. The timing of this sudden rise of NO_x emissions varies between the different tests, the cause of this is unknown. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.
In UDC tests with a hot start, the NO_x emissions are consistent at a level between 2700 and 3000 mg per ECE cycle and the EGR recirculation appears to be stable.

Partial conclusion 6:
UDC tests with a cold start that were conducted on the test track and on the dynamometer show a similar NO_x emissions trend. After a number of ECE cycles, the NO_x emissions suddenly increase from about 200 to 2000 mg per ECE cycle. The absolute NO_x and CO_2 emissions on the dynamometer are somewhat lower than on the test track. These lower emissions on the dynamometer are primarily due to the lower engine load in the dynamometer tests that may also be associated with other engine adjustments compared to the same test on the test track (for example, fuel injection strategy).

4.3 Controlling for the effect of the SEMS and the driver aid on the measurement results

The possible effect of the SEMS and the driver aid (an instrument that instructs the driver on the speed pattern to be followed) on NO_x emission behaviour was investigated by connecting the SEMS and the driver aid to an external battery (instead of the vehicle battery) in the 4*UDC test of 25-04-2018. Based on the test results (see Figure 4-23), it appears that the NO_x jump also occurs in this test. This means that the energy consumption of the SEMS and the driver aid connected to the vehicle battery does not seem to have any influence on the emission behaviour of this vehicle.

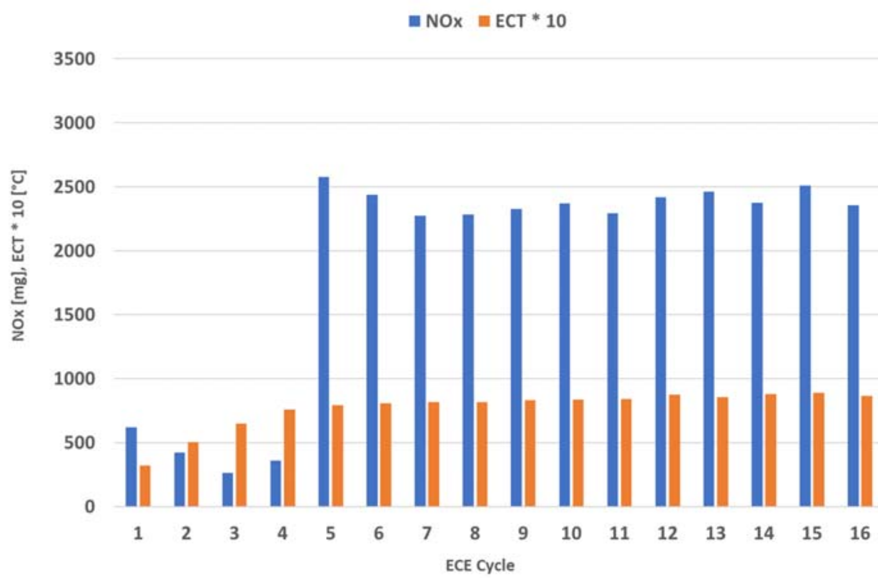

Figure 4-23: NO_x emissions per ECE cycle of a 4*UDC test with cold tart and engine calibration C1, performed on 25-05-2018. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 25 °C. The SEMS and the driver aid were connected to an external power supply. Preconditioning 3*EUDC with hot start.

Partial conclusion 7:
The NO_x emission behaviour of the tested vehicle is not influenced by the type of power source of the SEMS and the driver aid. Using the battery of the vehicle or an external battery as the power source for the SEMS and the driver aid does not seem to have any measurable influence on the NO_x emissions.

4.4 Verification of the track test emissions on the dynamometer

The majority of this study was conducted on the test track of the RDW. These test results have been verified by repeating certain tests on the dynamometer.
The emissions in a type-approval test were also verified with measurements on the dynamometer.

4.4.1 *Verification emissions in an NEDC type-approval test*

This section deals with sub-objectives 1 of section 1.2, and the following research question in particular: To what extent does the tested vehicle meet the Euro 5a limit values?

Background:
A vehicle manufacturer must perform In Service Conformity (ISC) test programmes with a limited number of vehicles of a certain model by conducting NEDC type-approval tests. ISC programmes are intended to check whether vehicles meet the applicable emission requirements. Vehicles under five years old or with a maximum mileage of 100,000 km must meet the ISC requirements. The tested Jeep Grand Cherokee Euro 5 diesel was named on 17 January 2013 and was tested on the dynamometer in August 2018 at a mileage of 85,181 km.

Execution:
The vehicle has been tested on the dynamometer in various test cycles, including the NEDC test cycle. The tests were performed with reference fuel and with various driving resistance curves. Prior to the NEDC tests, preconditioning tests were conducted on the dynamometer (3*EUDC), after which the vehicle was conditioned for more than 6 hours in a room with a temperature of 23 °C. The temperature of the dynamometer room was 23 °C during the tests.

Result:
Table 4-4 shows the Euro 5a limit values, the results of the NEDC type-approval test for this vehicle model (OEM Type approval) and the results of an NEDC test. With the OEM road load (RL1), the NEDC NO_x emission is 199 mg/km.
This is 11 % higher than the limit. In addition, the CO_2 emissions of 241 g/km is 7% higher than the value of 225 g/km measured by the manufacturer. The CO_2 emissions declared by the manufacturer is 218 g/km. The measured CO_2 emissions of 241 g/km indicates a relatively higher engine load in the NEDC test of this study, which also causes the NO_x emissions to be higher than the measured values in the type-approval.

Despite the test with a slightly increased engine load providing results that exceeded the NO_x limit value of 180 mg/km after an odometer reading of 85,181 km by 11%, it can nevertheless be stated that the vehicle with engine calibration C1 performs in line with the type-approval measurements.

Table 4-4: Limit values and measured values in NEDC cold start emissions tests with engine calibration C1

	CO_2	**CO**	**NO_x**	**THC+NO_x**	**PM**	**PN**
	[g/km]	**[mg/km]**	**[mg/km]**	**[mg/km]**	**[mg/km]**	**[#/km]**
Euro 5a limit values	-	500	180	230	5.0	-
NEDC RL 1*	225	228	142	170	1.0	-
NEDC RL 1	241	393	199	156	0.4	$8.0 * 10^8$

*OEM type-approval

Partial conclusion 8:
In an NEDC test with an original engine calibration C1 which has been conducted according to the type-approval test requirements, the CO_2 emissions are 241 g/km. This is 7% higher than the measured type-approval value. The measured NO_x emissions are 199 mg/km, this is 11% above the Euro 5 limit. Therefore, the measurements slightly exceed the Euro 5 limits.

4.4.2 *Effects of the different driving resistance curves on the emissions*

This section deals with sub-objectives 3 of section 1.2, and the following research question in particular: What is the effect of different driving resistance curves on exhaust emissions?

Background:
In a dynamometer test, the total driving resistance and weight of a vehicle is simulated by the dynamometer. In order to simulate this, the driving resistance curve of the test vehicle is first determined on the road and then these values are set on the dynamometer.
It is generally known that driving resistance curves determined in accordance with the test procedure in the type-approval results in low values.
The driving resistance curves of the test vehicle are shown in section 4.1.
There still appears to be a very substantial difference between the manufacturer's driving resistance curve and the established driving resistance curve on the RDW test track. Since this test programme has been carried out on both the dynamometer and on the road, it is important to have a good overview of the differences in test results.

Execution:
The test vehicle was tested on the dynamometer with the manufacturer's driving resistance curve (RL 1) as well as with a driving resistance curve determined on the straight sections of the test track in Lelystad (RL 2).
For comparison, a result has been added of a test that was performed on the test track (RL 4).

Result:
In Table 4-5 the results from two NEDC tests with two different driving resistance curves on the dynamometer (RL 1 and RL 2) and an NEDC test on the test track in Lelystad (RL 4) are shown. With an increase in driving resistance (RL 1 to RL 2), CO_2 emissions increase from 241 to 246 g/km. The NO_x emissions also increase from 199 to 290 mg/km.
On the test track in Lelystad, the driving resistance is relatively high, resulting in CO_2 emissions of 283 g/km and NO_x emissions of 983 mg/km in the NEDC test.

Table 4-5: Measurements in NEDC emission tests with engine calibration C1 with different dynamometer settings and on the RDW test track (RL 4) at an ambient temperatures of 23 and 21 °C.

	CO_2	**CO**	**NO_x**	**THC+NO_x**	**PM**	**PN**
	[g/km]	**[mg/km]**	**[mg/km]**	**[mg/km]**	**[mg/km]**	**[#/km]**
NEDC RL 1	241	393	199	156	0.4	$8.0 * 10^{8}$
NEDC RL 2	246	308	290	194	0.4	$5.2 * 10^{10}$
NEDC RL 4*	283	-	983	-	-	-

* Test results of exploratory emission study from 2016

Partial conclusion 9:
From the results of the NEDC tests with the original engine calibration C1 on the dynamometer with different resistance curves and on the test track, it appears that the CO_2 and NO_x emissions (strongly) increase when the resistance increases. On the test track, testing is carried out with the highest driving resistance. An increase in the resistance to motion results in an increase in the engine load, which, in this testing programme, leads to an increase in CO_2 emissions from 241 to 283 g/km (+ 17%) and an increase in NO_x emission from 199 to 983 mg/km (+ 394%).

4.4.3 *Comparison of SEMS emission results with dynamometer emission results*

This section deals with sub-objectives 7 of section 1.2, and the following research question in particular: What is the quality of the SEMS in comparison with the measurement results of the dynamometer?

Background:
The measuring systems of the dynamometer differ from the mobile measuring system, SEMS. The legally prescribed method on the dynamometer is conducted with a dilution tunnel with a constant flow rate and sampling with a continuous flow volume. This exhaust gas is collected in bags and subsequently analysed in exhaust gas analysers.
The SEMS is equipped with an NO_x-O_2 sensor in the exhaust and uses sensors that were fitted into the vehicle through the On Board Diagnostics (OBD) system. Both measuring systems have been used in this study.

Execution:
In a couple of dynamometer tests a validation of the SEMS was conducted with the measuring equipment of the dynamometer. Both measuring systems were operating simultaneously.

Result:
The CO_2 emissions of five different emission tests are shown in Figure 4-24. The measured SEMS CO_2 emissions are 11-13% (on average 12%) higher than those measured with the legally prescribed dynamometer method.

Figure 4-25 shows the NO_x emissions. The measured SEMS NO_x emissions are 17-23% (on average 19%) higher than those measured with the legally prescribed dynamometer method.

Analysis:
In the NEDC and UDC tests that were repeated, equal differences in CO_2 and NO_x emissions were measured. All measured SEMS CO_2 and NO_x emissions are higher than the emissions from the dynamometer and this deviation is fairly consistent per component. This indicates a systematic deviation from the SEMS and high repeatability.

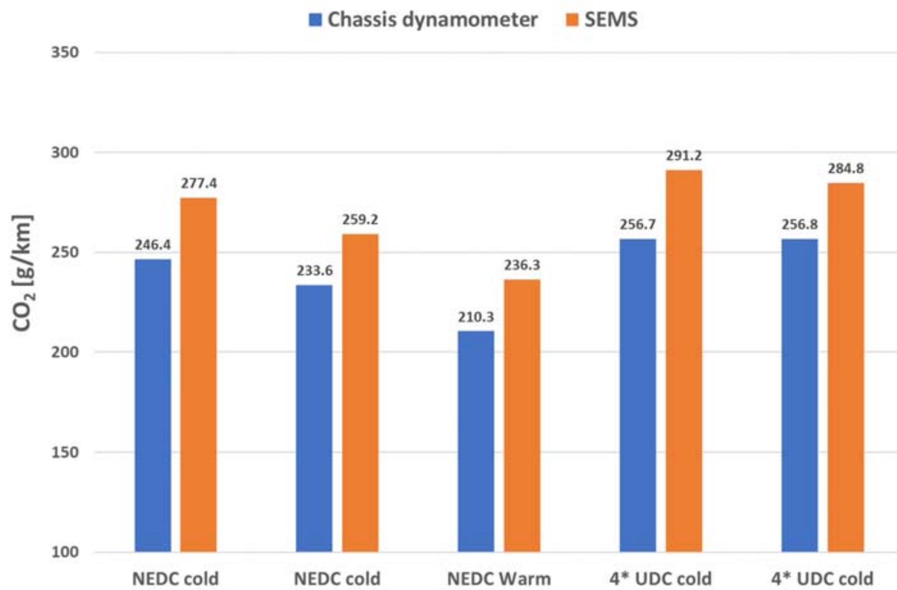

Figure 4-24: CO_2 emissions from different dynamometer tests measured with the dynamometer (chassis dynamometer) equipment and with the SEMS

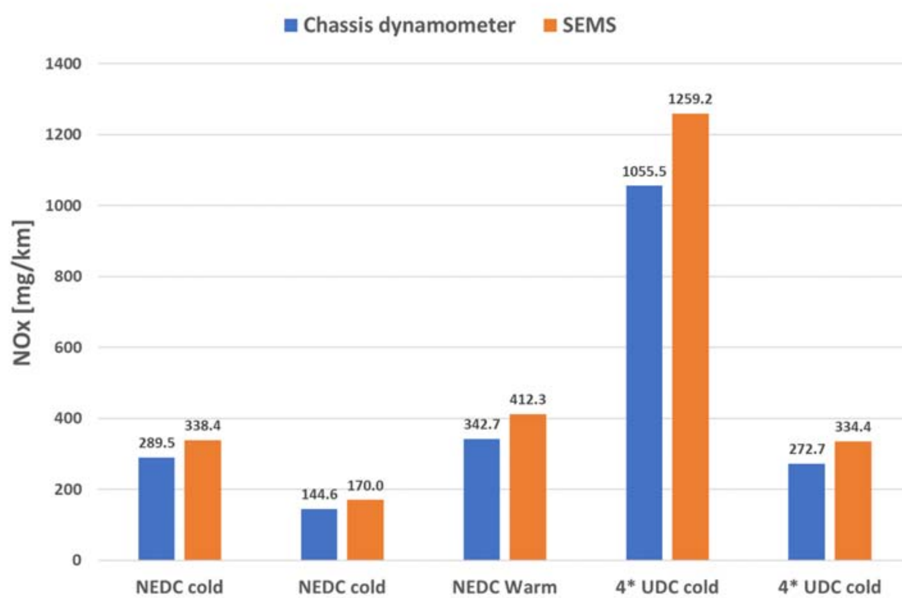

Figure 4-25: NO_x emissions from five dynamometer tests measured with the dynamometer (chassis dynamometer) equipment and with the SEMS

Partial conclusion 10:
The absolute CO_2 and NO_x emissions of this Jeep Grand Cherokee, measured with the SEMS measuring system, are higher than the given value that was determined based on the legally prescribed measuring method on a dynamometer. The relative deviations are 11-13% for CO_2 and 17-23% for NO_x and these are fairly consistent across significantly different emission levels in the five tests conducted. For the partial conclusions in this study, the abovementioned deviations of the SEMS have no impact because all the measurements were carried out using the SEMS and the measured deviations for the different emission levels are constant.

4.5 Verification of emissions after update of engine calibration

This section deals with sub-objectives 8 and 10 of section 1.2, and the following research question in particular: What is the effect of the new engine calibration on the emissions of the Jeep Grand Cherokee Euro 5a diesel?

Background:
In 2017, the manufacturer announced that an improved engine calibration will become available for this vehicle model. In the course of the dynamometer programme, which took place in August 2018, the manufacturer installed a new engine calibration in the test vehicle. The manufacturer verbally stated that their field of expertise in EGR control has been expanded, so that larger quantities of EGR are supplied under more operating conditions. The explanation did not contain any information about any adjustments to the starting conditions of the EGR control of the engine.

Execution:
During the dynamometer programme, the manufacturer checked the test vehicle with the original engine calibration and the vehicle was found to be in good condition. After this check, the new engine calibration (for identification numbers see Table 3-1) was installed and an active soot filter regeneration was carried out. The regeneration of the soot filter took place with a stationary vehicle at an engine speed of 3000 rpm and lasted about 20 minutes.

A number of emission tests with this new engine calibration were then carried out on the dynamometer, on the test track and on public roads, which are reported in sections 4.4.1 and 4.4.2.

4.5.1 Dynamometer
Table 4-6 and Figure 4-26 present the NO_x emissions from the different NEDC tests that were conducted on the dynamometer. The driving resistance curves (RL1 and RL2), the starting conditions of c and h (cold and hot) and the engine calibrations (C1 and C2) were varied.
Due to an increase in driving resistance (RL 1 to RL2), the NO_x emissions in an NEDC cold start test with engine calibration C1 increased from 199 to 290 mg/km and the CO_2 emissions increased from 241 to 246 g/km.
In the NEDC test with a warm start and engine calibration C1, in comparison to a cold start test (c to h), the NO_x emissions increased from 199 to 1498 mg/km and the CO_2 emissions decreased from 241 to 214 g/km.
In an NEDC cold start test, engine calibration C2 reduces NO_x emissions from 199 to 145 mg/km (-27%).

In an NEDC test with engine calibration C2 and a hot start, the NO_x emissions drop from 1498 to 343 mg/km (-77%), despite the higher driving resistance of engine calibration C2 in comparison to engine calibration C1. In Figure 4-26, the cumulative NO_x emissions of the NEDC tests are shown graphically.

Table 4-6: NEDC test results with cold and hot starts (c and h), two different driving resistance curves (RL1 and RL2), and two different engine calibrations (C1 & C2)

	CO_2	CO	NO_x	THC+NO_x	PM	PN
	[g/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[#/km]
NEDC c RL1 C1	241	393	199	156	0.4	$8.0 * 10^8$
NEDC c RL2 C1	246	308	290	194	0.4	$5.2 * 10^{10}$
NEDC c RL1 C2	234	439	145	184	0.2	$6.7 * E^{10}$
NEDC h RL1 C1	214	26	1498	1525	0.4	$2.5 * 10^{10}$
NEDC h RL2 C2	210	27	343	349	0.3	$1.7 * 10^8$

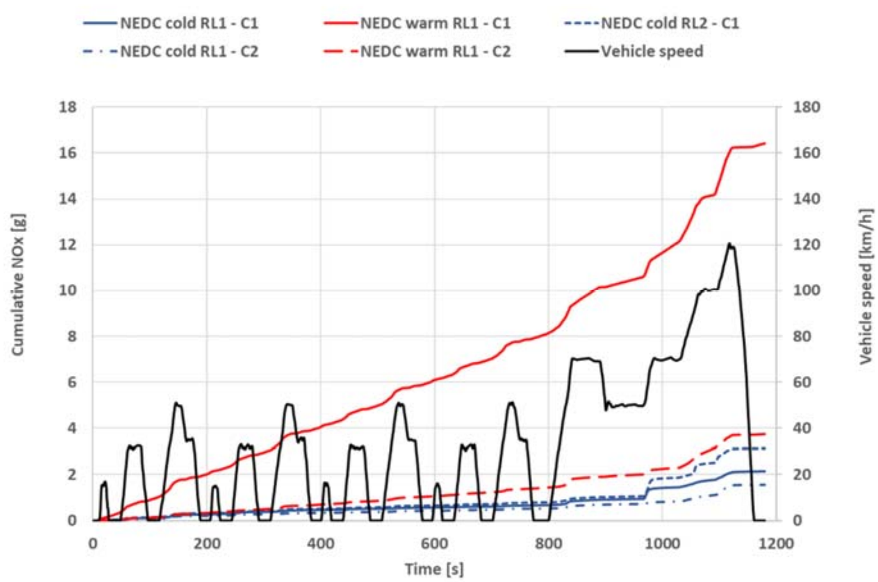

Figure 4-26: Cumulative representation of the NO_x emissions from NEDC tests with cold and hot starts (c and h), two different driving resistance curves (RL1 and RL2), and two different engine calibrations (C1 & C2)

The cumulative CO_2 emissions of the NEDC tests performed are shown in Figure 4-27. This shows that the differences in CO_2 emissions before and after the software update are much smaller than the differences in NO_x emissions.

The NO_x emissions from UDC tests per ECE cycle are shown in Figure 4-28 for engine calibrations C1 and C2. In the first UDC test with engine calibration C1, a soot filter regeneration was carried out and there are lower NO_x emissions in ECE cycles 7 to 11.

After approximately eight ECE cycles, engine calibration C1 shows a NO_x increase by a factor of 8-10 (from approx. 0.2 to 2.0 g per ECE cycle). In the case of engine calibration C2, the NO_x increases around ECE cycle 8 by a factor of 2 (from approx. 0.2 to 0.4 g per ECE cycle).

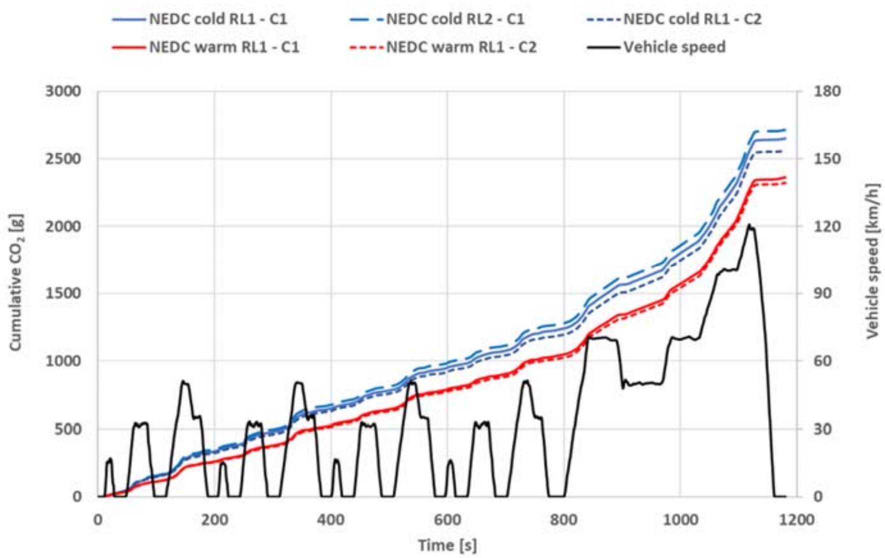

Figure 4-27: Cumulative representation of CO_2 emissions from NEDC tests with cold and hot starts (c & h), two different driving resistance curves (RL1 and RL2) and two different engine calibrations (C1 & C2).

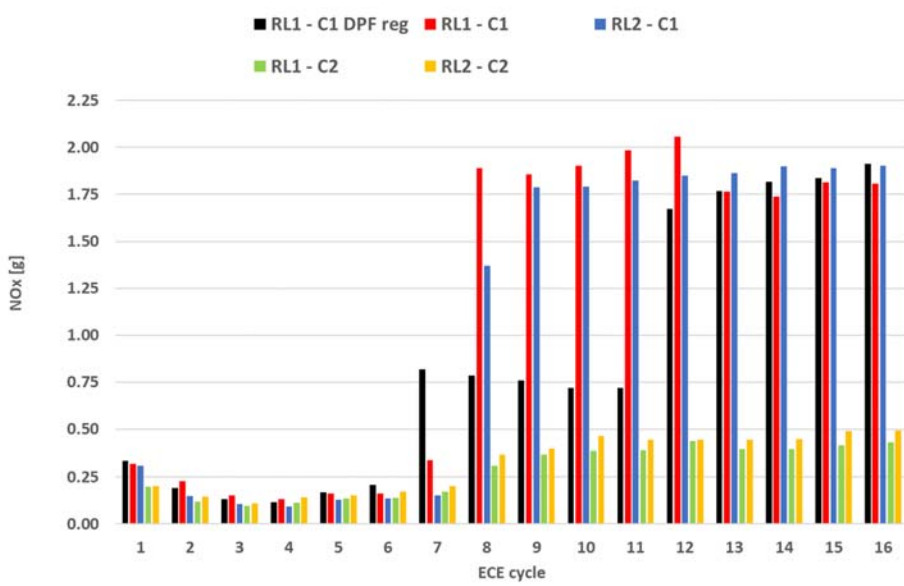

Figure 4-28: NO_x emissions per ECE cycle of UDC cold start tests, performed on the dynamometer with two engine calibrations (C1 & C2), two dynamometer settings (RL1, RL2), at an ambient temperature of 23 °C. Preconditioning 3* EUDC with hot start. A soot filter regeneration was carried out in the first test (black).

4.5.2 *Test track and public road*

A few tests were performed on the test track with engine calibration C2.
In Figure 4-29, the trend of various parameters and the NO_x emissions of an NEDC test with a cold start are shown. The NO_x emissions are 376 mg/km and the EGR system was active (IAT > 50 °C) during the entire test. When this is compared to the NEDC test with engine calibration C1 (see Figure 4-5) with NO_x emissions of 1319 mg/km, it becomes clear that the difference in NO_x emissions arises in the EUDC part (from 780 to 1180 seconds).

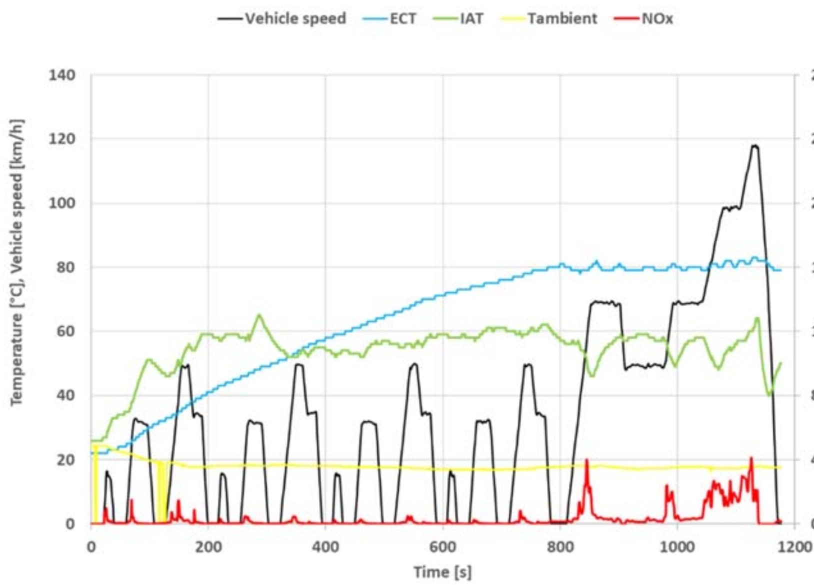

Figure 4-29: NEDC test with engine calibration C2 and cold start of 18-10-2018 on the test track, at an ambient temperature of 18 °C. The inlet temperature was 50-60 °C for almost the entire test, indicating an active EGR system. CO_2 = 312 g/km and NO_x = 376 mg/km.

The NO_x emissions at a constant speed were also measured on the test track with engine calibration C2. In Figure 4-30, it can be seen that after about 300 seconds, or after having travelled a distance of 12 kilometres at a constant speed of 125 km/h, the inlet temperature (IAT) decreases from about 70 to 25 °C and the NO_x emissions increase from 25 to 50-65 mg/s. This increase in NO_x emissions is primarily caused by a reduction of the added quantity of EGR.

In addition, UDC tests with engine calibration C2 were performed on the test track. Figure 4-31 shows the NO_x emissions per ECE cycle. After 1500 seconds, the NO_x emissions per ECE cycle rises from approx. 170 to 500 mg. Despite this increase to 500 mg per ECE cycle, this emission is low in comparison to the measured NO_x emissions of 2500 mg in ECE cycles with engine calibration C1.
From Figure 4-32, it can be seen that the inlet temperature (IAT) decreases from about 70 to 60 °C and the NO_x emissions increase simultaneously from 170 to 500 mg per ECE cycle. This also indicates a reduction in the added quantity of EGR.

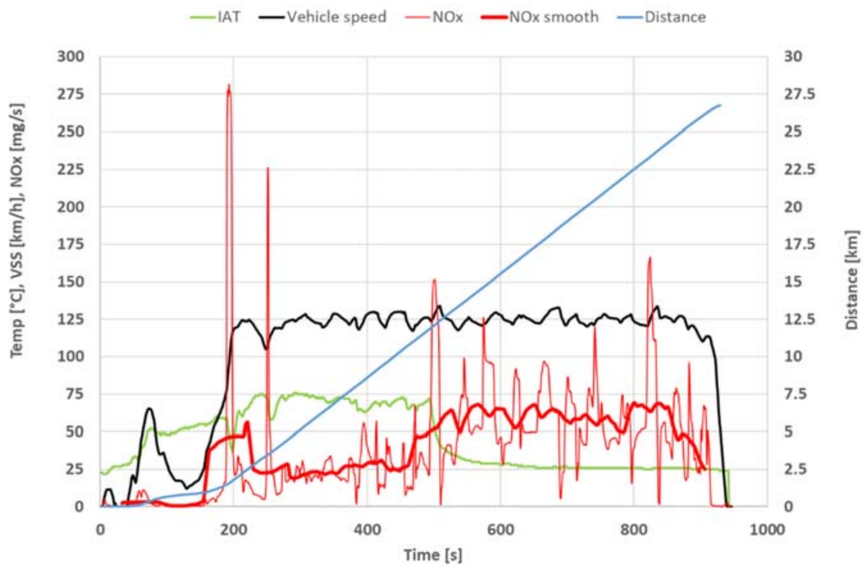

Figure 4-30: Test at a constant speed of 125 km/h with engine calibration C2 and a cold start of 23-10-2018 on the test track. The inlet temperature at 500 seconds is around 70 °C. The inlet temperature then drops to 25 °C and the NO_x emissions increase from approx. 25 to 50-65 mg/s. This indicates a reduction in the added quantity of EGR.

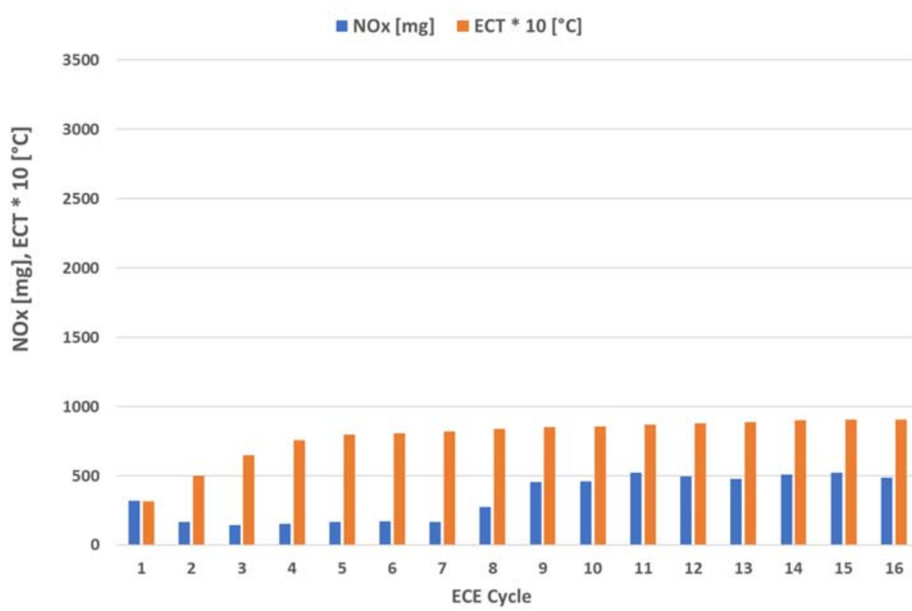

Figure 4-31: NO_x emissions per ECE cycle with engine calibration C2 in a 4*UDC test with cold start, performed on 24-10-2018. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 18 °C. Preconditioning 3*EUDC with hot start.

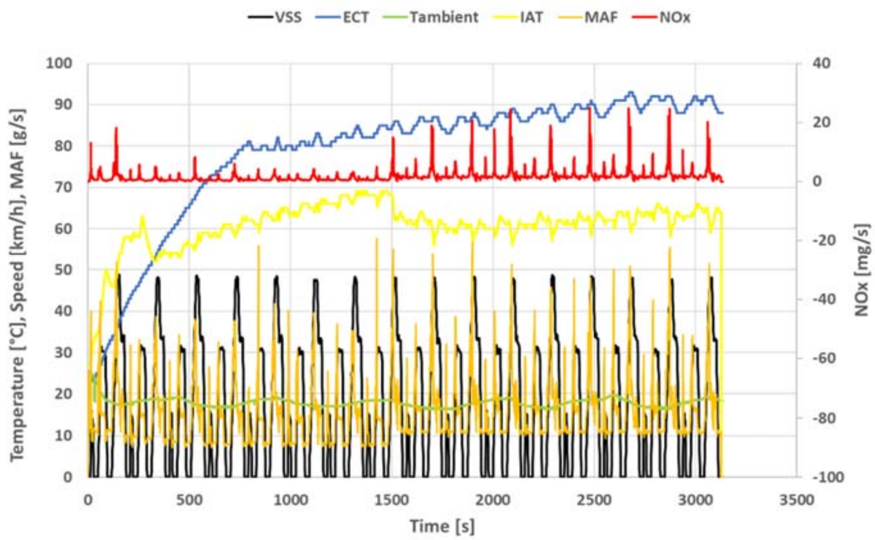

Figure 4-32: 4*UDC test with a cold start and engine calibration C2, performed on 24-10-2018. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW with an ambient temperature of 18 °C. Preconditioning 3* EUDC with hot start. After 1500 seconds, the inlet temperature drops from 70 to 60 °C and the NO_x emissions increase.

In Table 4-7 and Figure 4-33, the CO_2 and NO_x emission results of the RDE tests that were conducted with the two engine calibrations are shown. For a hot start with engine calibration C1, NO_x emissions of 1807-2170 mg/km were measured at ambient temperatures of 5.5 to 23 °C. For a hot start with engine calibration C2, NO_x emissions of 599-796 mg/km were measured at ambient temperatures of 11.6 to 27.5 °C. This is a reduction of approximately 65-70% compared to the RDE tests with engine calibration C1. The air consumption with engine calibration C2 is 200-214 kg per RDE test and has decreased by a quarter compared to the RDE tests with engine calibration C1 (previously 276-295 kg). This decrease in air consumption is a result of an increase in the added quantity of EGR.
The soot filter appears to be regenerated more frequently in RDE tests with engine calibration C2.

Table 4-7: CO_2, NO_x and air consumption results of RDE tests of the Jeep Grand Cherokee Euro 5a diesel conducted in Lelystad with two different engine calibrations

Date	**Calibration Start**	**T environment**	**CO_2**	**NO_x**	**Air consumption**
		[°C]	[g/km]	[mg/km]	[kg]
16-3-2018	1 – hot	5.5	275	2170	294.9
20-3-2018*	1 – hot	11.5	260	1889	286.3
20-6-2018	1 – hot	23	262	1807	276.1
2-10-2018*	2 – hot	11.6	301	796	213.9
3-10-2018	2 - cold	14.5	272	558	200.0
4-10-2018*	2 – hot	16	280	627	204.7
5-10-2018*	2 – hot	20	280	774	206.8
13-10-2018	2 - hot	27.5	275	599	202.6

*Regeneration of the soot filter

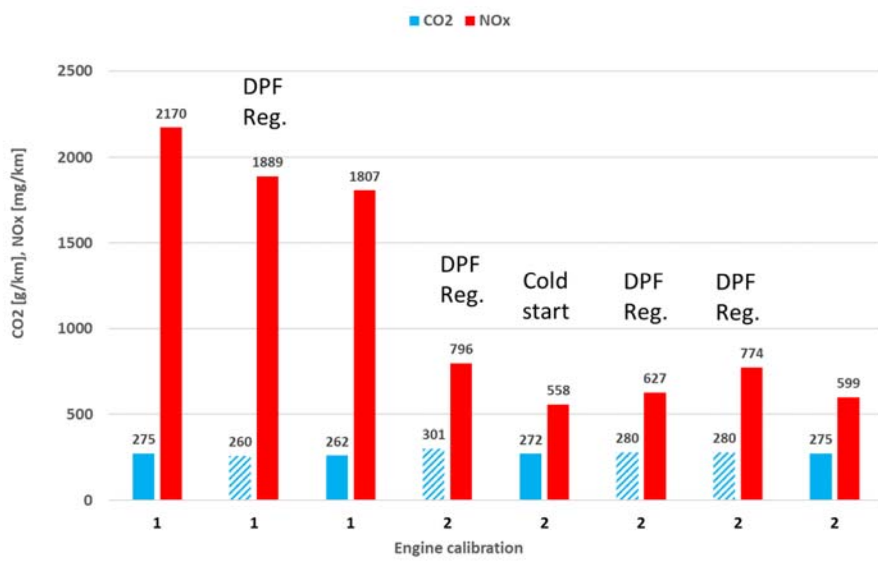

Figure 4-33: CO_2 and NO_x results from RDE tests of the Jeep Grand Cherokee Euro 5a diesel conducted in Lelystad with two different engine calibrations

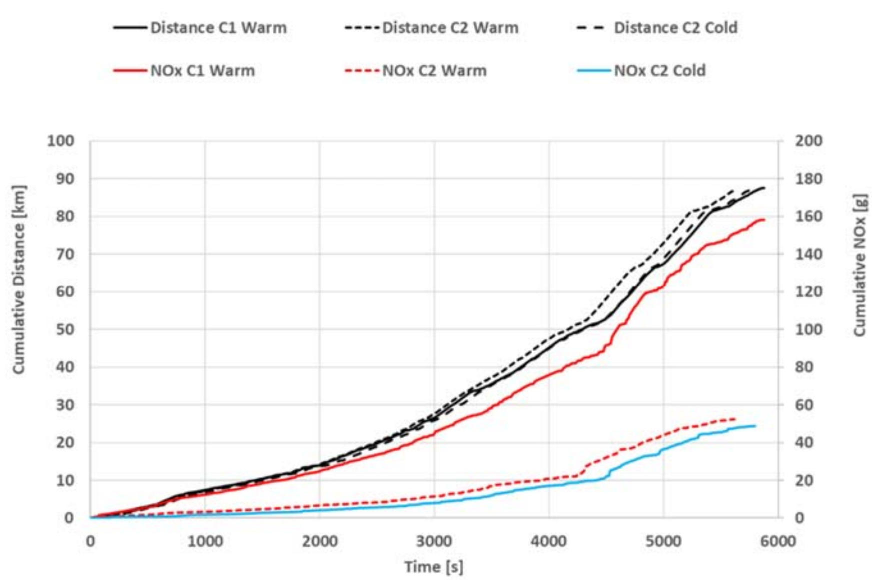

Figure 4-34: Cumulative NO_x results from RDE tests of the Jeep Grand Cherokee Euro 5 diesel conducted in Lelystad with two different engine calibrations

Partial conclusion 11:

The NO_x emissions of the Jeep Grand Cherokee Euro 5a diesel decreased considerably after the update of the engine calibration (C2).

This was established in the following tests:

1. In the NEDC type-approval test on the dynamometer with both engine calibrations and with a cold start, the NO_x emissions of 199 and 145 mg/km are relatively constant and are around the limit value of 180 mg/km. On the test track, this NEDC test with a cold start with both engine calibrations was carried out with an ambient temperature of 24 and 18 °C, resulting in a decrease in NO_x emissions from 1319 to 376 mg/km with engine calibration C2.
2. In the RDE tests with a hot start that were performed on the public road, the NO_x emissions decrease after the update of the engine calibration from 1807-2170 to 599-774 mg/km. Starting conditions (cold start and hot start) with engine calibration C2 only have a very limited influence on the NO_x emission levels in RDE testing.
3. In UDC tests with a cold start with engine calibration C1 that were conducted on the dynamometer and on the test track, the NO_x emissions increase quite abruptly 1500 seconds after the cold start, from approximately 250 mg per ECE cycle to 1750-2750 mg per ECE cycle. With engine calibration C2, this NO_x increase is much smaller at approx. 170 to 500 mg per ECE cycle.

In an NEDC type-approval test on the chassis dynamometer with a cold start, the NO_x emissions with the two engine calibrations are around the limit value of 180 mg/km. Under daily practical conditions on public roads, the average NO_x emissions with engine calibration C2 fall to around 700 mg/km (approx. 65% reduction in comparison to 2000 mg/km with engine calibration C1).

5 Discussion

Are the emission tests of the Jeep Grand Cherokee Euro 5a diesel conducted on the dynamometer comparable to the tests on the test track?
Emission tests on a dynamometer are well defined because the European emissions legislation for road vehicles accurately describes these tests.

This is particularly applicable to the following components:

- Prescribed test equipment
- Simulation of the driving resistance curve and vehicle weight
- Vehicle preconditioning
- The ambient temperature and humidity in the test laboratory
- The lack of external influences (wind, precipitation, slopes in the road)
- High-quality test equipment that is calibrated for each test

Based on the legally prescribed requirements, this is not possible on the RDW test track in Lelystad. Environmental conditions are different and the test procedures (such as preconditioning) are performed slightly differently on certain points than they are on the dynamometer. Furthermore, the test track consists of two straight road sections and two bends, which leads to significant differences in the effective driving resistance curve compared to the dynamometer. In addition, the environmental conditions such as the outside temperature and the wind force and wind direction are different each day. The SEMS emission measurement system used also has different properties than the dynamometer measuring equipment.

The measured differences in CO_2 emissions from similar tests at the same ambient temperatures on the dynamometer and on test track can be explained because the test vehicle undergoes a higher driving resistance on the test track than it does on the dynamometer. However, on the test track, the NO_x emissions from similar tests always prove to be considerably higher those on the dynamometer. It is specifically the abovementioned environmental conditions and the effective driving resistance which lead to more severe test conditions on the test track and, thus, cause the NO_x emissions to rise significantly in comparison to the emissions on the dynamometer.

What are the considerations for applying Exhaust Gas Recirculation (EGR)?
The Jeep Grand Cherokee is equipped with an EGR system that allows a certain amount of unfiltered exhaust gas to flow back into the engine under certain conditions. Exhaust Gas Recirculation, or EGR, is primarily used to reduce NO_x emissions. The supply of cooled exhaust gas to the intake air of the engine reduces the amount of oxygen available in the engine, resulting in a reduction in NO_x emissions.

What effect does engine calibration C2 have?
The manufacturer stated orally that practical research through field tests have shown that the safety margins have been reduced with regard to durability of the new engine calibration. The EGR index field has therefore been extended in engine calibration C2 and the conditions for the active application of EGR have been adjusted.

The results of this study indicate that the NO_x emissions in engine calibration C2 have decreased significantly in comparison to engine calibration C1, while the CO_2 emissions have increased slightly. The sustainability effects of engine calibration C2 on emissions has not been investigated, as only instantaneous measurements have been performed.

6 Conclusions

In 2018, the Netherlands Vehicle Authority (RDW) commissioned TNO to carry out an emission study of the Jeep Grand Cherokee Euro 5a diesel.
The goal of the study was to map the Jeep Grand Cherokee emission behaviour, measured with 2 different engine calibrations (C1 & C2).
To this end, several partial objectives were formulated and emission measurements were carried out on a test track of the RDW, on a dynamometer and on public roads.

When taken together, the results of these measurements provide a good overview of the emission behaviour of the tested vehicle and the differences in emissions before and after the update of the engine calibration software. The conducted tests provide limited insight into the applied EGR regulation strategy.
The partial conclusions based on the performed measurements have been included below:

Partial conclusion 1:
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 0.5 to 10 times higher than the driving resistance curve determined by the manufacturer. The absolute difference in driving resistance force is constant over the speed range of 10-130 km/h and is approximately 600-700 N. This difference is largely caused by the turns in the test track.

Partial conclusion 2:
Two Jeep Grand Cherokee Euro 5 diesel vehicles with the original engine calibration C1 were tested. The first was tested in the RDW study of 2017 and the second was tested in this study. In both cases, the emission tests on the test track showed that the vehicles significantly exceed the NO_x limit value of 180 mg/km and have similar emission behaviour.

Partial conclusion 3:
Based on NEDC testing with a cold start of the Jeep Grand Cherokee Euro 5 diesel with the original engine calibration C1, which was performed on the test track in different ambient temperatures, it appears that the NO_x emissions increase from approx. 1000 to more than 3500 mg/km when the ambient temperature decreases from 21 to 2 °C. The corresponding CO_2 emissions increase from 281 to 358 g/km. This indicates that the NO_x and CO_2 emissions of the Jeep Grand Cherokee Euro 5 diesel with its original engine calibration are heavily dependent on the ambient temperature.

Partial conclusion 4:
In the NEDC testing with the original engine calibration C1 and a hot start on the test track, the NO_x emissions were up to twice as high as in the NEDC test of the cold start on the test track (1874 versus to 970 mg/km). On the dynamometer, the emissions are almost eight times higher (1498 versus 199 mg/km). There are differences between NO_x emissions in NEDC tests with a cold start and in those with a hot start. There are also differences in the tests on the dynamometer versus those on the test track.

All these differences can be primarily attributed to the different amounts of exhaust gas that flow back to the engine (EGR), caused by the active control of the EGR valve by the operating system of the engine. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.

Partial conclusion 5:
In UDC tests of engine calibration C1 with a cold start, it appears that over time the NO_x emissions abruptly rise from approximately 250 to 1750-2750 mg per ECE cycle. A similar rise in NO_x emissions is measured in the test with a constant speed of 50 km/h. The increase in NO_x emissions is primarily caused by the adjusted method of controlling the EGR system, which regulations the quantity of EGR. The timing of this sudden increase in NO_x emissions varies in the different tests, but the cause of this is unknown. Other engine parameters (such as the fuel injection strategy) may also influence the NO_x emissions. These have not been examined in the study.
In UDC tests with a hot start, the NO_x emissions are consistent at a level between 2700 and 3000 mg per ECE cycle and the EGR recirculation appears to be stable.

Partial conclusion 6:
UDC tests with engine calibration C1 and a cold start that were performed on the test track and on the dynamometer show a similar NO_x emissions trend.
After a number of ECE cycles, the NO_x emissions suddenly increase from about 200 to 2000 mg per ECE cycle. The absolute NO_x and CO_2 emissions on the dynamometer are somewhat lower than on the test track. These lower emissions on the dynamometer are primarily caused by the lower engine load in the dynamometer tests that may also be associated with other engine adjustments compared to the same test on the test track (for example, fuel injection strategy).

Partial conclusion 7:
The NO_x emissions behaviour of the tested vehicle is not influenced by the type of power source of the SEMS and the driver aid.
Using the battery of the vehicle or an external battery as the power source for the SEMS and the driver aid does not seem to have any measurable influence on the NO_x emissions.

Partial conclusion 8:
In an NEDC test with the original engine calibration C1 which is carried out according to the type-approval test requirements, the CO_2 emissions are 241 g/km, which is 7% higher than the measured type-approval value. The measured NO_x emissions are 199 mg/km, which is 11% above the Euro 5 limit value. Therefore, the measurements slightly exceed the Euro 5 limits.

Partial conclusion 9:
e results of the NEDC tests with the original engine calibration C1 conducted on the dynamometer with different resistance curves and on the test track, it appears that the CO_2 and NO_x emissions (significantly) increase when the resistance increases. On the test track, testing is carried out with the highest driving resistance. An increase in the resistance to motion results in an increase in the engine load, which, in this testing programme, leads to an increase in CO_2 emissions from 241 to 283 g/km (+ 17%) and an increase in NO_x emission from 199 to 983 mg/km (+ 394%).
Partial conclusion 10:

The absolute CO_2 and NO_x emissions of this Jeep Grand Cherokee, measured with the SEMS measuring system, are higher than the given value that was determined based on the legally prescribed measuring method on a dynamometer.

The relative deviations are 11-13% for CO_2 and 17-23% for NO_x and these are fairly consistent across significantly different emission levels in the five tests conducted. For the partial conclusions in this study, the abovementioned deviations of the SEMS have no impact because all the measurements were carried out using the SEMS and the measured deviations for the different emission levels are constant.

Partial conclusion 11:
The NO_x emissions of the Jeep Grand Cherokee Euro 5a diesel decreased considerably after the update of the engine calibration (C2).

This was established in the following tests:
1. In the NEDC type-approval test on the chassis dynamometer, with both engine calibrations and with a cold start, the NO_x emissions are fairly constant at 199 and 145 mg/km and around the limit value of 180 mg/km. On the test track, this NEDC test with a cold start with both engine calibrations was carried out with an ambient temperature of 24 and 18 °C, resulting in a decrease in NO_x emissions from 1319 to 376 mg/km with engine calibration C2.
2. In the RDE tests with a hot start that were performed on public roads, the NO_x emissions decrease after the update of the engine calibration from 1807-2170 to 599-774 mg/km. Starting conditions (cold start and hot start) with engine calibration C2 only have a very limited influence on the NO_x emission levels in RDE testing.
3. In UDC tests with a cold start with engine calibration C1 that were conducted on the dynamometer and on the test track, the NO_x emissions increase abruptly 1500 seconds after the cold start, from approximately 250 mg per ECE cycle to 1750-2750 mg per ECE cycle. With engine calibration C2, the NO_x increase of approx. 170 to 500 mg per ECE cycle is much lower.

In an NEDC type-approval test on the chassis dynamometer with a cold start, the NO_x emissions with the two engine calibrations are around the limit value of 180 mg/km. Under daily practical conditions on public roads, the average NO_x emissions with engine calibration C2 fall to around 700 mg/km (approx. 65% reduction in comparison to 2000 mg/km with engine calibration C1).

Partial conclusion 12:
Just like engine calibration C1, the emission behaviour of engine calibration C2 is not constant. The NO_x emissions in UDC tests increase with engine calibration C2 after approximately 1500 seconds, from 170 to 500 mg per ECE cycle, while the added quantity of EGR decreases.

7 Abbreviations

ADC	Analogue Digital Convertor
CO	Carbon monoxide
CO_2	Carbon dioxide
ECE	United Nations Economic Commission for Europe
ECT	Engine Coolant Temperature
EGR	Exhaust Gas Recirculation
EUDC	Extra Urban Driving Cycle
IAT	Inlet Air Temperature
ISC	In Service Conformity
NO_x	Nitrogen oxides
THC	Total Hydrocarbons
MAF	Mass Air Flow rate
NEDC	New European Driving Cycle
OBD	On Board Diagnostics
OEM	Original Equipment Manufacturer
PEMS	Portable Emission Measurement System
PM	Particulate Matter
PN	Particle Number
RDW	Netherlands Vehicle Authority
RDE	Real Driving Emissions
SEMS	Smart Emission Measurement System
TA	Type Approval
TCL	Test Centre Lelystad
TNO	Netherlands Organisation for Applied Scientific Research
UDC	Urban Driving Cycle
VSS	Vehicle Speed Sensor

8 References

[RDW 2017] Emissions Tests Programme RDW, July 2017, RDW

9 Signature

The Hague, 3 May 2019

Peter J. van der Mark
Project manager

TNO

Gerrit Kadijk
Author

A Reference fuel certificates

Haltermann Carless

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Schlengendeich 17 21107 Hamburg Germany

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HANS-MESS-STRASSE 6
61440 OBERURSEL

Certificate 100000143845

Date: 17.08.2018
Customer PO: 4510755815
Delivery Note: 80122222 000010
Order No.: 68118574 000010
Customer No.: 1750282

GMID: 283508
Material: Diesel, CEC Legislative Fuel RF-06-08 B5 (EU-V Cert.)
172 KG LINED STEEL DRUM 1A1
Cust. Mat.:
Batch: GF1103T475
Orig. Batch: 37
Sample No.: 30035518
Analyzed: 11.06.2018
Divy. Qty: 172,0 KG

Vehicle: OD-FT1610/WL-TL1123
Ship from: Shipping Point Hamburg Hamburg 02 Germany

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Feature	Units	Results	Limits Minimum	Maximum	Method
Cetane Number (CFR)	(*1)	52,2	52,0	54,0	DIN EN ISO 5165:1998-05
Density at 15°C (*2)	kg/m3	833,9	833,0	837,0	DIN EN ISO 3675:1998-11
Density @ 15degC	kg/m3	833,9			DIN EN ISO 12185:1997-11
Specific Gravity		0,8344 @ 15/15degC			DIN EN ISO 12185:1997-11
Distillation IBP	°C	206,2			DIN EN ISO 3405:2011-04
Dist. 50% v/v	°C	283,8	245,0	-	DIN EN ISO 3405:2011-04
Dist. 95% v/v	°C	347,0	345,0	350,0	DIN EN ISO 3405:2011-04
Distillation FBP	°C	356,1	-	370,0	DIN EN ISO 3405:2011-04
Flash Point	°C	90,0	55,0	-	DIN EN ISO 2719:2016-11
CFPP	°C	-20	-	-5	DIN EN 116:2018-04
Viscosity at 40°C	mm2/s	3,043	2,300	3,300	DIN EN ISO 3104:1999-12
Aromatics, Poly (2+3)	% w	3,6	2,0	6,0	DIN EN 12916:2016-06
Aromatics, Total	% w	20,0			DIN EN 12916:2016-06
Aromatics, Mono	% w	16,4			DIN EN 12916:2016-06
Aromatics, Di	% w	3,5			DIN EN 12916:2016-06
Aromatics, Tri +	% w	0,1			DIN EN 12916:2016-06
Sulfur	mg/kg	< 3,0	-	10,0	DIN EN ISO 20846:2012-01
Corrosion - Copper	-	1A max. 1	-	-	DIN EN ISO 2160:1999-04
Carbon Residue - 1	% w	< 0,10	-	0,20	DIN EN ISO 10370:2015-03
Ash Content (*1)	% w	< 0,001	-	0,010	DIN EN ISO 6245:2003-01

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Feature	Units	Results	Limits Minimum	Maximum	Method
Water	mg/kg	52	-	200	DIN EN ISO 12937:2002-03
Water & Sediment	%(V)	< 0,010			ASTM D6304:2016
Strong Acid Number	mg	< 0,02 KOH/g	-	0,02	ASTM D974:2014
Oxidation Stabilit (*2)	g/m3	< 1	-	25	DIN EN ISO 12205:1996-01
Oxidation Stability	Hour	67,2	20,0		DIN EN 15751:2014-06
HFRR (WSD) 12156-1:2016-11	µm	182	-	400	DIN EN ISO
FAME	%(V)	5,3	4,5	5,5	DIN EN 14078:2014-09
Oxygen Content	% w	0,67 calculated			DIN EN 14078:2014-09
Hydrogen (*2)	% w	13,48			RWL-HM-28
Carbon (*2)	% w	85,84			RWL-HM-28
C:H Ratio (H = 1) (*2)		6,37			RWL-HM-28
H:C Ratio (C = 1) (*2)		0,157			RWL-HM-28
Net Heating Value (*2)	MJ/kg	42,952			RWL-HM-27
Net Heating Value (*2)	Btu/lb	18464			RWL-HM-27
Pour Point	°C	-44	-	-	ASTM D6892:2003

(*1) : tested by subcontractor
(*2) : not accredited
(*3) : modified

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The analyses were conducted in our DIN EN ISO/IEC 17025 accredited laboratory.
Robert Geisler, Phone + +49-40-33318-149

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NIEDERLASSUNG OBERURSEL
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Certificate 100000009514

Date: 18.07.2012
Customer PO: 4500816580
Delivery Note: 80006449 000010
Order No.: 66015961 000010
Customer No.: 1750283

GMID: 283508
Material: Diesel, CEC Legislative Fuel RF-06-08 B5 (EU-V Cert.)
172 KG LINED STEEL DRUM 1A1
Cust. Mat.:
Dlvy. Qty: 172,0 KG
Orig. Batch:
Analyzed: 20.04.2012

Im Lager vorhanden

Vehicle: OD-SK 460/OD-SK 462
Ship from: Shipping Point Hamburg Hamburg 02 Germany Page: 1 / 2

Feature	Units	Results AD230300B5	Limits Minimum	Maximum	Method
Cetane Number (CFR		52,6	52,0	54,0	EN ISO 5165
		tested by subcontractor			
Density @ 15degC	kg/m3	834	833	837	EN ISO 3675
Density @ 15degC	kg/m3	834,1			EN ISO 12185
Specific Gravity		0,8346			EN ISO 12185
		@ 15/15degC			
Distillation IBP	°C	199,1			EN ISO 3405
Dist. 50% v/v	°C	278,0	245,0	-	EN ISO 3405
Dist. 95% v/v	°C	348,8	345,0	350,0	EN ISO 3405
Distillation FBP	°C	360,2	-	370,0	EN ISO 3405
Flash Point	°C	84	55	-	EN ISO 2719
CFPP	°C	-20	-	-5	EN 116
Viscosity @ 40degC	mm2/s	2,875	2,300	3,300	EN ISO 3104
Aromatics, Poly (2	% w	4,6	2,0	6,0	EN 12916
Aromatics, Total	% w	21,4			EN 12916
Aromatics, Mono	% w	16,8			EN 12916
Aromatics, Di	% w	4,6			EN 12916
Aromatics, Tri+	% w	< 0,1			EN 12916
Sulfur	mg/kg	< 3,0	-	10,0	EN ISO 20846
Corrosion - Copper	-	1A	-	-	EN ISO 2160
		max. 1			
Carbon Residue	% w	< 0,10	-	0,20	EN ISO 10370
		10% Dist. Residue			
Ash Content	% w	< 0,001	-	0,010	EN ISO 6245
		tested by subcontractor			
Water	mg/kg	28	-	200	EN ISO 12937
Strong Acid Number	mg	< 0,01	-	0,02	ASTM D974
		KOH/g			
Oxidation Stabilit	g/m3	< 1	-	25	EN ISO 12205

Sitz der Gesellschaft: Hamburg, Amtsgericht Hamburg * HRB 118570 * Steuernummer 41 660 10094 * Geschäftsführer: Dr. Uwe Nickel
Commerzbank AG * Konto 6152128 * Bankleitzahl 20040000 * IBAN DE20 2004 0000 0615 2128 00 * SWIFT Code COBADEFFXXX

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2 / 2

Feature	Units	Results AD230300B5	Limits Minimum	Maximum	Method
Oxidation Stabilit	h	78,0	20,0	-	EN 14112
		modified			
HFRR (wsd 1,4)	µm	184	-	400	EN ISO 12156-1
FAME	%(V)	5,0	4,5	5,5	EN 14078
Oxygen Content	% w	0,63			EN 14078
		calculated			
Carbon	% w	85,92			ASTM D3343
		modified			
Hydrogen	% w	13,45			ASTM D3343
		modified			
C:H Ratio (H= 1)		6,39			ASTM D3343
		modified			
H:C Ratio (C= 1)		0,157			ASTM D3343
		modified			
Net Heating Value	MJ/kg	42,944			ASTM D3338
		modified			
Net Heating Value	Btu/lb	18461			ASTM D3338
		modified			

The certificate is electronically generated and valid without signature.

Laboratory is accredited acc DIN EN ISO / IEC 17025, DAkkS D-PL-17640-01-00
Christine Behrens, Phone + + 49-40-33318-136

Sitz der Gesellschaft: Hamburg, Amtsgericht Hamburg * HRB 118570 * Steuernummer 41 660 10094 * Geschäftsführer: Dr. Uwe Nickel
Commerzbank AG * Konto 6152128 * Bankleitzahl 20040000 * IBAN DE20 2004 0000 0615 2128 00 * SWIFT Code COBADEFFXXX

B Results of dynamometer emission testing

	Test type	Road	Calibration	Phase	HC	CO	CO2	NOx	NO	NMHC	CH4	NMOG	HC+NOx	FC	PM	PN
		Load			[mg/km]	[mg/km]	[g/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[l/100km]	[mg/km]	[1/km]
15-8-2018	UDC cold	1	1	1	93.8	1068.0	308.1	172.1	119.9	75.9	10.6	88.0	265.9	11.77		2.15E+09
15-8-2018	EUDC	1	1	2	8.1	7.0	203.4	214.4	114.3	4.4	0.0	8.8	222.5	7.72		2.33E+07
15-8-2018	NEDC cold	1	1	1+2	39.3	393.0	241.5	199.1	116.3	30.4	10.1		238.4	9.20	0.37	7.96E+08
22-8-2018	UDC cold	2	1	1	72.1	832.0	317.2	200.7	136.7	53.2	12.5	63.2	272.8	12.10		1.43E+11
22-8-2018	EUDC	2	1	2	6.2	7.0	205.9	340.5	179.6	3.3	0.0	7.1	346.7	7.82		8.83E+07
22-8-2018	NEDC cold	2	1	1+2	30.2	307.5	246.4	289.5	163.7	21.4	10.0		319.8	9.38	0.37	5.20E+10
29-8-2018	UDC cold	1	2	1	95.1	1185.0	298.0	136.7	98.8	73.8	13.9	86.0	231.8	11.40		1.83E+11
29-8-2018	EUDC	1	2	2	7.5	13.0	196.8	149.1	76.4	2.0	1.2	6.5	156.6	7.48		2.44E+08
29-8-2018	NEDC cold	1	2	1+2	39.2	438.9	233.6	144.6	84.4	28.1	12.6	183.7	183.8	8.90	0.23	6.67E+10
15-8-2018	UDC warm	1	1	1	54.1	59.0	257.1	1989.0	1270.7	51.5	0.0	62.9	2043.1	9.77		5.21E+08
15-8-2018	EUDC	1	1	2	11.8	7.0	189.1	1216.0	630.7	11.5	0.0	15.9	1227.8	7.18		3.89E+10
15-8-2018	NEDC Warm	1	1	1+2	27.4	25.8	213.9	1497.7	864.0	26.1	1.4	1525.0	319.8	8.13	0.40	2.49E+10
29-8-2018	UDC warm	2	2	1	11.2	37.0	252.1	351.7	180.2	5.4	0.0	14.2	362.9	9.58		3.36E+08
29-8-2018	EUDC	2	2	2	2.5	22.0	186.3	338.0	158.4	0.7	0.0	5.0	340.5	7.08		7.94E+07
29-8-2018	NEDC Warm	2	2	1+2	5.8	27.2	210.3	342.7	166.3	2.4	3.8	348.5	348.5	7.99	0.27	1.73E+08

	Test type	Road Load	Calibration	Phase	HC	CO	CO2	NOx	NO	NMHC	CH4	NMOG	HC+NOx	FC	PM	PN
					[mg/km]	[mg/km]	[g/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[l/100km]	[mg/km]	[1/km]
16-8-2018	UDC cold	1	1	1	117.4	1188.0	296.6	192.6	136.7	99.2	13.8	109.8	310.1	11.35		2.23E+09
16-8-2018	UDC cold	1	1	2	57.8	21.0	376.8	484.0	275.9	25.2	29.5	33.6	541.8	14.32		5.14E+10
16-8-2018	UDC cold	1	1	3	23.0	20.0	418.5	940.8	539.3	6.9	9.2	15.5	963.7	15.90		1.50E+12
16-8-2018	UDC cold	1	1	4	9.9	14.0	242.1	1803.2	851.9	6.3	0.0	12.5	1813.2	9.19		1.31E+11
16-8-2018	4* UDC cold	1	1	1-5	52.1	310.2	333.6	855.3	451.0	34.3	20.3	907.4	907.4	12.69	9.94	4.21E+11
23-8-2018	UDC cold	1	1	1	93.8	1205.0	292.0	159.1	111.8	73.8	13.2	85.6	252.9	11.17		3.28E+10
23-8-2018	UDC cold	1	1	2	23.0	14.0	256.4	421.9	246.1	12.3	1.8	22.0	444.9	9.74		6.16E+07
23-8-2018	UDC cold	1	1	3	30.4	14.0	240.7	1779.6	1035.2	26.9	0.0	36.2	1810.1	9.15		7.32E+07
23-8-2018	UDC cold	1	1	4	31.1	20.0	237.6	1859.8	1091.7	27.9	0.0	36.9	1890.8	9.03		5.71E+07
23-8-2018	4* UDC cold	1	1	1-5	44.5	313.5	256.7	1055.5	621.6	35.3	10.5	1099.9	1099.9	9.77	0.13	8.24E+09
21-8-2018	UDC cold	2	1	1	90.7	1076.0	295.4	172.7	117.4	72.2	15.8	80.1	263.5	11.29		7.16E+11
21-8-2018	UDC cold	2	1	2	21.1	17.0	261.9	492.1	279.6	11.3	4.9	17.3	513.3	9.95		1.83E+08
21-8-2018	UDC cold	2	1	3	26.1	12.0	247.7	1890.8	1079.3	23.0	0.0	29.2	1916.9	9.41		1.14E+08
21-8-2018	UDC cold	2	1	4	28.6	16.0	244.9	1935.6	1121.0	26.4	0.0	32.2	1964.2	9.31		1.00E+08
21-8-2018	4* UDC cold	2	1	1-5	41.6	279.1	262.4	1124.4	650.3	33.2	9.6	1166.0	1166.1	9.99	0.30	1.78E+11
24-8-2018	UDC cold	2	1	1	73.3	868.0	307.6	207.5	144.8	55.0	12.3	64.8	280.9	11.74		3.55E+09
24-8-2018	UDC cold	2	1	2	18.6	16.0	266.7	607.1	346.1	9.7	0.9	18.9	625.7	10.13		3.79E+07
24-8-2018	UDC cold	2	1	3	24.2	16.0	252.0	1925.6	1101.7	20.6	0.0	29.6	1949.9	9.57		2.89E+07
24-8-2018	UDC cold	2	1	4	20.5	21.0	248.4	1757.2	965.6	17.5	0.0	26.4	1777.7	9.44		1.89E+07
24-8-2018	4* UDC cold	2	1	1-5	34.0	227.7	268.5	1126.4	640.3	25.6	9.6	1160.4	1160.3	10.22	0.13	8.98E+08
30-8-2018	UDC cold	1	2	1	119.3	1516.0	289.3	126.8	92.6	94.5	16.7	109.2	246.1	11.09		9.89E+10
30-8-2018	UDC cold	1	2	2	18.6	25.0	254.6	182.7	96.3	7.6	0.1	19.2	201.3	9.67		1.28E+08
30-8-2018	UDC cold	1	2	3	15.5	18.0	243.3	382.1	188.3	9.8	0.0	21.1	397.7	9.24		1.27E+08
30-8-2018	UDC cold	1	2	4	13.7	12.0	239.8	397.7	190.1	8.1	0.0	18.9	411.3	9.11		1.22E+08
30-8-2018	4* UDC cold	1	2	1-5	41.8	393.0	256.8	272.7	141.9	30.0	13.6	314.5	314.5	9.78	0.28	2.48E+10
31-8-2018	UDC cold	2	2	1	86.4	1067.0	303.1	145.4	100.7	63.3	14.2	76.7	231.8	11.59		7.68E+09
31-8-2018	UDC cold	2	2	2	15.5	109.0	269.8	215.6	106.9	4.2	1.4	15.0	231.1	10.26		6.61E+07
31-8-2018	UDC cold	2	2	3	11.8	16.0	259.4	428.1	199.5	5.3	0.0	15.9	439.9	9.85		5.36E+07
31-8-2018	UDC cold	2	2	4	11.2	19.0	260.2	461.7	219.3	5.5	0.0	15.9	472.9	9.89		4.23E+07
31-8-2018	4* UDC cold	2	2	1-5	31.2	303.5	273.2	312.2	156.3	19.6	13.2	343.4	343.4	10.40	0.28	1.97E+09

C Results of test track emission testing

No	Calibration		Start	Date	Tambient	Time	CO2	NOx
			Cold/warm		[°C]		[g/km]	[mg/km]
1	1		warm	12-3-2018		16:15	333	2695
2	1	NEDC warm	warm	13-3-2018	8	9:12	320	2771
3	1	NEDC No Start	warm	13-3-2018	8	13:05	407	1689
4	1	EUDC-UDC	warm	13-3-2018	7	13:28	307	2543
5	1	NEDC cold	cold	14-3-2018	8	7:47	317	2908
6	1	NEDC warm	warm	14-3-2018	14	13:49	309	2568
7	1		warm	14-3-2018	14	14:11	291	2468
8	1	130 kph	warm	14-3-2018	14	14:52	367	2992
9	1	NEDC warm	warm	14-3-2018	14	15:17	287	2498
10	1	3* EUDC	warm	14-3-2018	14	15:39	247	2104
11	1	NEDC cold	cold	15-3-2018	9	7:03	320	2832
12	1	130 kph	warm	15-3-2018	9	8:07	385	3539
13	1	NEDC warm	warm	15-3-2018	9	8:13	299	2581
14	1	3* EUDC	warm	15-3-2018	10	8:49	254	2108
15	1	NEDC cold	cold	16-3-2018	10	7:09	326	2833
16	1	NEDC warm	warm	16-3-2018	8	7:32	306	2644
17	1	NEDC warm	warm	16-3-2018	7	7:54	310	2692
18	1	130 kph	warm	16-3-2018	7	9:25	390	3257
19	1	NEDC +10%	warm	16-3-2018	7	9:39	310	2667
20	1	NEDC -10%	warm	16-3-2018	7	10:01	287	2457
21	1	EUDC-UDC	warm	16-3-2018	7	10:33	298	2521
22	1	RDE	warm	16-3-2018	6	12:48	275	2171
23	1	130 kph	warm	16-3-2018	5	15:04	365	2963
24	1	3* EUDC	warm	16-3-2018	5	15:15	268	2397
25	1	NEDC cold	cold	20-3-2018	10	7:51	-	-
26	1	NEDC warm	warm	20-3-2018	9	8:13	288	2501
27	1	NEDC AUX	warm	20-3-2018	9	8:35	296	2584
28	1		warm	20-3-2018	10	9:53	307	2131
29	1	NEDC +10%	warm	20-3-2018	11	10:05	279	2303
30	1	NEDC -10%	warm	20-3-2018	12	10:27	260	2199
31	1	EUDC-UDC	warm	20-3-2018	11	11:10	273	2377
32	1	RDE	warm	20-3-2018	11	12:34	254	1847
33	1	3* EUDC	warm	20-3-2018	12	14:26	238	2083
34	1	NEDC cold	cold	21-3-2018	2	7:31	358	3670
35	1	NEDC warm	warm	21-3-2018	2	7:52	286	2538
36	1	NEDC +10%	warm	21-3-2018	5	8:14	303	2671
37	1	EUDC - UDC	warm	21-3-2018	7	8:36	287	2483
38	1	130 kph	warm	21-3-2018	9	9:52	354	2968
39	1	NEDC No Start	warm	21-3-2018	9	10:17	330	2944
40	1	130 kph	warm	27-3-2018	13	11:39	416	3857
41	1	3* EUDC	warm	27-3-2018	12	11:56	253	2399

No	Calibration		Start	Date	Tambient	Time	CO2	NOx
			Cold/warm		[°C]		[g/km]	[mg/km]
42	1	4* UDC	cold	28-3-2018	13	08:12	365	3002
43	1	120 kph	warm	28-3-2018	11	10:03	306	2179
44	1	4* UDC	warm	28-3-2018	10	10:14	339	2801
45	1	130 kph	warm	30-3-2018	9	7:03	398	3442
46	1	3* EUDC	warm	30-3-2018	8	7:23	256	2114
47	1	4* UDC	cold	3-4-2018	19	13:21	369	1731
48	1	130 kph	warm	3-4-2018	19	15:02	351	2313
49	1	4* UDC	warm	3-4-2018	20	15:15	341	2792
50	1	120 kph	warm	3-4-2018	20	16:34	316	1814
51	1	3* EUDC	warm	3-4-2018	20	16:40	237	1797
52	1	4* UDC	cold	9-4-2018	21	14:51	348	2157
53	1	4* UDC	warm	9-4-2018	20	16:01	415	2293
54	1	3* EUDC	warm	9-4-2018	19	16:56	234	1790
55	1	50* kph	cold	10-4-2018	22	13:17	159	875
56	1	50* kph	warm	10-4-2018	23	14:23	150	1032
57	1	120* kph	cold	11-4-2018	21	16:18	368	2305
58	1	3* EUDC	warm	11-4-2018	21	16:31	238	1756
59	1	100* kph	cold	13-4-2018	19	13:20	246	1402
60	1	100* kph	warm	13-4-2018	19	14:30	243	1401
61	1	180* -180 kph	warm	18-4-2018	26	12:55	415	3474
62	1	3* EUDC	warm	18-4-2018	26	13:17	232	1823
63	1	4* UDC	cold	19-4-2018	27	10:45	336	2130
64	1	4* UDC	warm	19-4-2018	29	12:53	316	2946
65	1	3* EUDC	warm	19-4-2018	30	13:48	239	1934
66	1	4* UDC	cold	24-4-2018	15	08:19	361	2310
67	1	4* UDC	warm	24-4-2018	15	09:55	343	2503
68	1	3* EUDC	warm	24-4-2018	15	10:50	259	2097
69	1		cold	7-5-2018	28	19:13	302	1532
70	1	3* EUDC	warm	7-5-2018	27	19:37	262	1876
71	1	4* UDC	cold	8-5-2018	27	10:38	354	1684
72	1	120* kph	warm	8-5-2018	30	15:37	334	2110
73	1	3* EUDC	warm	8-5-2018	30	16:13	254	1891
74	1		cold	9-5-2018	27	13:59	319	703
75	1	3* EUDC	cold	11-5-2018	16	08:33	297	2095
76	1		cold	22-5-2018	24	13:58	309	1319
77	1		warm	22-5-2018	24	14:22	283	2195
78	1	3* EUDC	warm	22-5-2018	24	14:50	254	1717
79	1	4* UDC	cold	23-5-2018	-	-	-	-
80	1	4* UDC	warm	23-5-2018	-	-	-	-
81	1	3* EUDC	warm	23-5-2018	27	15:43	253	1775
82	1	4* UDC	cold	25-5-2018	25	13:33	352	1954
83	1	120* kph	warm	25-5-2018	25	15:20	337	2364
84	1	4* UDC	warm	25-5-2018	26	15:32	321	2510
85	1	3* EUDC	warm	25-5-2018	26	16:26	246	1645
86	1		warm	20-6-2018	23	11:08	262	1807

No	Calibration		Start	Date	Tambient	Time	CO2	NOx
			Cold/warm		[°C]		[g/km]	[mg/km]
87	2	130* kph	cold	1-10-2018	12	10:42	405	886
88	2	RDE	warm	2-10-2018	13	11:40	301	796
89	2	RDE	cold	3-10-2018	15	11:53	272	558
90	2	RDE	warm	4-10-2018	16	11:35	280	627
91	2	RDE	warm	5-10-2018	20	14:42	280	774
92	2	4* UDC	cold	13-10-2018	24	11:30	423	578
93	2	RDE	warm	13-10-2018	28	13:09	275	599
94	2	3* EUDC	warm	13-10-2018	27	15:07	315	861
95	2	NEDC	cold	16-10-2018	19	09:32	295	288
96	2	130* kph	warm	16-10-2018	25	13:57	358	956
97	2	Co* Coast	warm	16-10-2018	25	14:10	305	1581
98	2	3* EUDC	warm	16-10-2018	24	15:25	253	475
99	2	NEDC	cold	18-10-2018	18	13:27	312	376
100	2	3* EUDC	warm	18-10-2018	17	13:51	257	464
101	2	130* kph	warm	23-10-2018	16	14:11	404	1320
102	2	3* EUDC	warm	23-10-2018	16	14:29	268	477
103	2	4* UDC	cold	24-10-2018	18	12:13	365	358
104	2	3* EUDC	warm	24-10-2018	18	13:27	263	473

D Dynamometer specifications

Horiba Europe GMBH performs emission tests in its laboratory in accordance with ISO 17025 standards and is certified to do this.

The following measuring equipment is installed in the test room:

Chassis Test Cell

Air conditioning
Weiss Umwelttechnik
Cooling performance 150 kW
Air circulation 30,000 m³/h
Fresh air 2,000 m³/h
CVS dilution air 1,200 m³/h
Waste air 2,000 – 4,000 m³/h

Chassis Dynamometer
VULCAN II EMS-CD48L 4WD
Max. speed 200 km/h
Max. capacity/power 2 x 155 kW
Wheel base 1800 – 3400 mm
Max. axle load 2,500 kg
Fan LTG VQF 500/1250

Exhaust Measurement Equipment
MEXA ONE D1-EGR
Exhaust gas analyser, undiluted (direct) for: O_2, CO, CO_2, NO_x/NO, THC and CH_4, separate EGR analyser

MEXA ONE C2-OV
Exhaust gas analyser, dilute bag & continuous measurement for: O_2, CO, CO_2, NO_x/NO, THC, CH4.

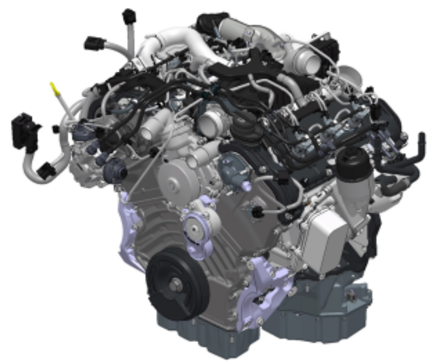
Heated Bag Cabinet
with 3 x 4 emission bags for measuring ambient air, gasoline and diesel.

MEXA 2100 SPCS
Measures solid particle number concentration in raw engine exhaust gas in real time, within a specified particle size range (UN/ECE Regulation).

- **Horiba MEXA ONE D1-EGR**
  Exhaust Gas Analysing System for direct measurement (1-line) with the following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH4 and separate EGR analyser.
- **Horiba MEXA ONE C2-OV**, Exhaust Gas Analysing System for dilute bag & continuous measurement with the following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH4.
- **Horiba MEXA 2100 SPCS**, Solid Particle Counting System.
- **Horiba MEXA ONE CVS**, Constant Volume Sampler System, 6 m^3/min to 18 m^3/h.
- **Horiba DLS 7000**, Particulate Measuring System with Dilution Tunnel DLT 18.
- Different temperature and pressure regulators (according to the test application), max. 16 temperature inputs (Type K) and 8 voltage and current analogue inputs.
- **Horiba VETS One**, Host Computer and evaluation of measuring data with DIVA.
- **Horiba PWS-ONE**, Particle measurement and conditioning chamber with micro balance and robot.

E Engine configuration details

A630 - V6 3.0L "Tomcat"
ENGINE PRESENTATION



VM Service

Cento - 01 Dicembre 2010

1

A630 EU.5 Technical Features & Performance

- Model: **JEEP Grand Cherokee** (WK)
- Type: SUV
- Application: Longitudinal
- Power&Torque: 176 kW (240CV) & 540 Nm
- Transmission: A580 (ATX)
- Emissions: Euro 5
- SOP: February 2011
- Production site: US

- Model: **CHRYSLER 300C** (LX)
- Type: Passenger Car
- Application: Longitudinal
- Power&Torque: 176 kW (240CV) & 550 Nm
- Transmission: A580 (ATX)
- Emissions Euro 5
- SOP: October 2011
- Site of production: US

2

Main Features

The 3.0L V6 Diesel Engine with common- rail direct injection is built at VM Motori engines plant in Cento Italy.

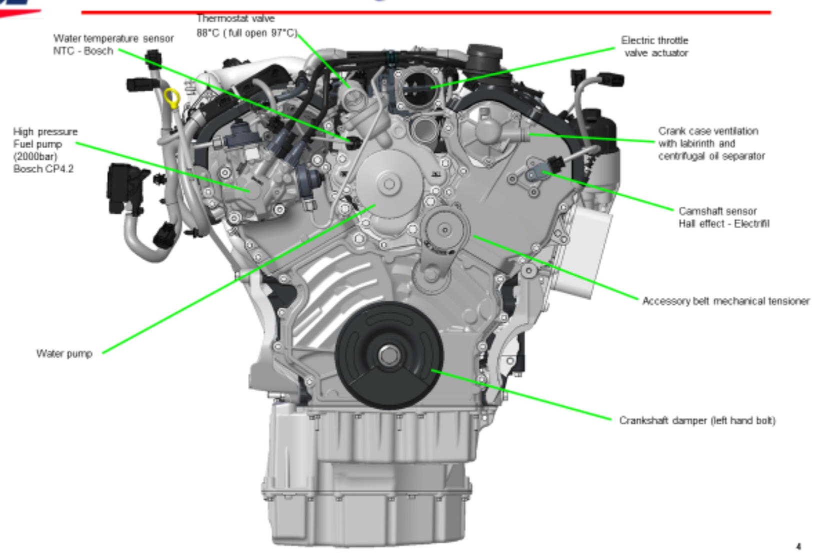
The main engine features are CGI block, dual overhead camshafts chain driven, central injectors and four valves per cylinder.

Additional features are:

- **Turbocharged and intercooler**
- **Finger Follower Actuated Valves with - Hydraulic Adjusters**
- **Oil Jet Cooled Pistons**
- **Swirl Intake Ports**
- **Water cooled exhaust gas recirculation Compliance with EURO V emission regulations**
- **Chain-driven double overhead camshafts per bank of cylinders, with 24 valves.**

3

A630 EU.5 Engine Overview – FRONT VIEW



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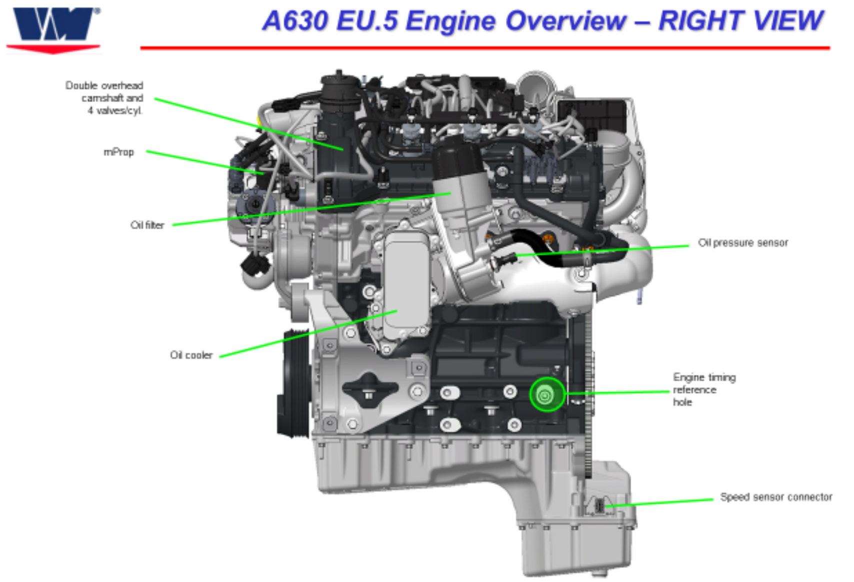
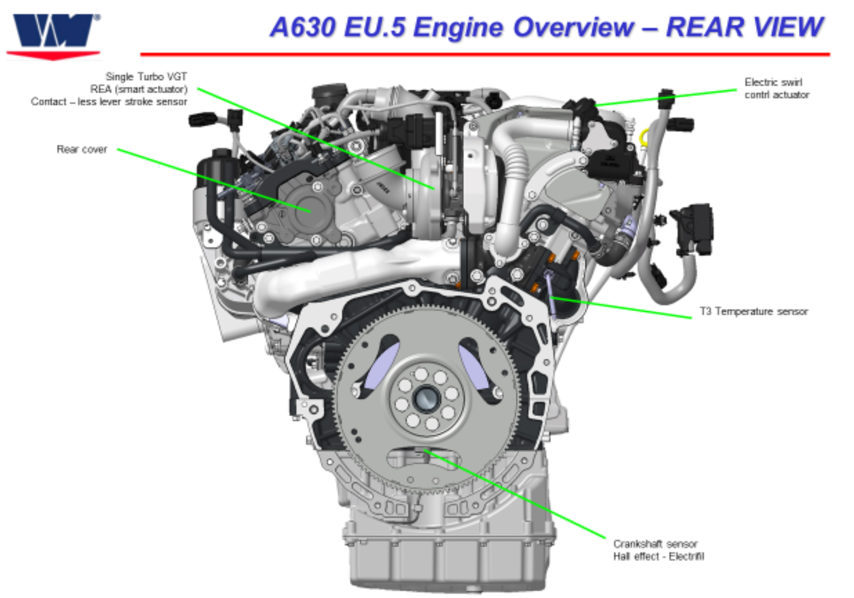
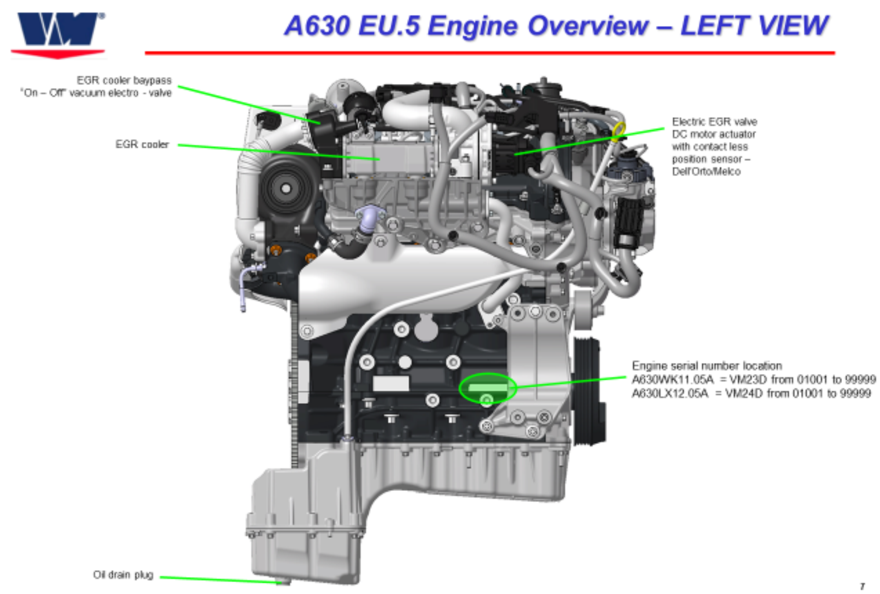
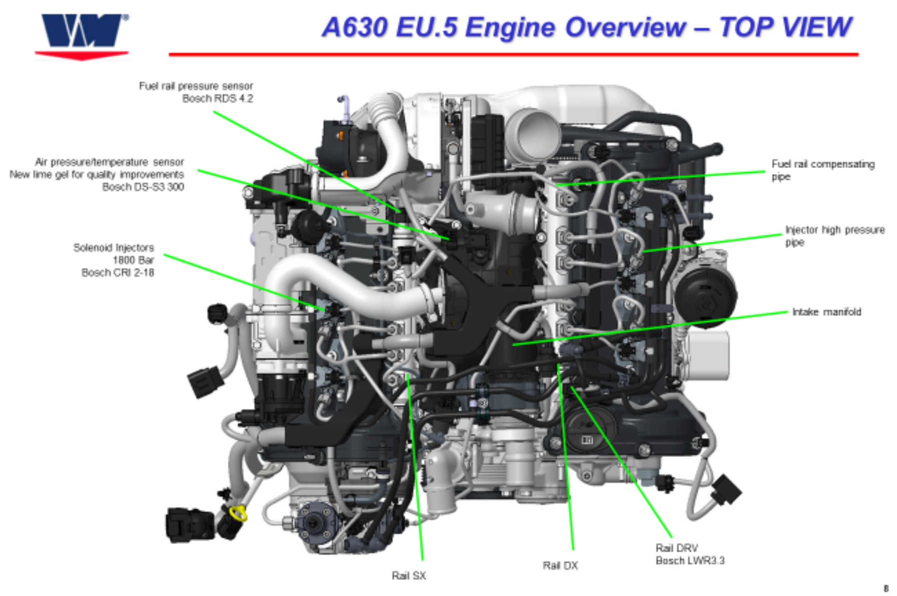

A630 EU.5 Engine Overview – RIGHT VIEW
Double overhead camshaft and 4 valves/cyl.
mProp
Oil filter
Oil pressure sensor
Oil cooler
Engine timing reference hole
Speed sensor connector
5


A630 EU.5 Engine Overview – REAR VIEW
Single Turbo VGT REA (smart actuator) Contact – less lever stroke sensor
Electric swirl contrl actuator
Rear cover
T3 Temperature sensor
Crankshaft sensor Hall effect - Electrifil
6


A630 EU.5 Engine Overview – LEFT VIEW
EGR cooler baypass
"On – Off" vacuum electro - valve
EGR cooler
Electric EGR valve
DC motor actuator
with contact less
position sensor –
Dell'Orto/Melco
Engine serial number location
A630WK11.05A = VM23D from 01001 to 99999
A630LX12.05A = VM24D from 01001 to 99999
Oil drain plug
7

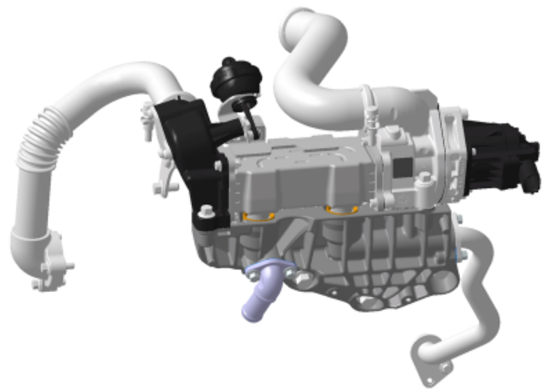

A630 EU.5 Engine Overview – TOP VIEW
Fuel rail pressure sensor
Bosch RDS 4.2
Air pressure/temperature sensor
New lime gel for quality improvements
Bosch DS-S3 300
Solenoid Injectors
1800 Bar
Bosch CRI 2-18
Fuel rail compensating
pipe
Injector high pressure
pipe
Intake manifold
Rail SX
Rail DX
Rail DRV
Bosch LWR3.3
8

Egr System

EGR Sistem with water cooled EGR Cooler and BY-PASS Valve.

Electrical EGR and Pneumatic BY-PASS Valve.

Sourcing Status: Supplier Selected Dellorto (for EGR System). Fondalmec (for the Bracket Assy).



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