Swedish In-Service Conformity Test Programme on Emissions from Passenger Cars and Light-Duty Trucks

Annual Report 2015

2015-12-31

by

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Content

1. List of Abbreviations

A4 / A5 / A6	4-speed / 5-speed / 6-speed automatic gearbox
CADC	Common Artemis Driving Cycle
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of production
CPC	Condensation Particle Counter
CVS	Constant Volume Sampler; exhaust emission sampling system
EC	European Community
EUDC	Extra Urban Driving Cycle; Part 2 of the New European Driving Cycle
Euro 1	Type approval test in accordance with Directive 91/441/EEC
Euro 2	Type approval test in accordance with Directive 94/12/EEC
Euro 3	Type approval test in accordance with Directive 98/69/EC
Euro 4	Type approval test in accordance with Directive 98/69/EC, stricter requirements (incl. lower limit values in driving cycle, -7°C test)
Euro 5, Euro 6	Type approval test in accordance with EU Regulation 715/2007/EC
FC	Fuel consumption
FTP 75	Federal Test Procedure 75 = US American driving cycle, defined in 1975
HC	Hydro carbons; see THC
KBA	Kraftfahrtbundesamt – German Federal Motor Transport Authority
M1	Vehicles for passenger transportation with a capacity of max. 8 seats excluding the driver and a maximum total vehicle mass of 3,500kg
M5 / M6	5-speed / 6-speed manual gearbox
MK	Miljöklass; Swedish Environmental Class
N1	Vehicles for transportation of goods and a total vehicle mass of up to 3,500kg
NEDC	New European Driving Cycle according to EU Regulation 715/2007/EC
NO_X	Nitrogen oxides
OBD	On-Board Diagnosis
PEMS	Portable Emission Measurement System
PM	Particle Mass
PMP	Particle Measurement Programme
PN	Particle Number
RPA	Relative Positive Acceleration
SHED	Sealed Housing for Evaporative Emissions Determination
STA	Swedish Transport Agency
THC	Total Mass of hydro carbons emitted by a vehicle, given in C_1 equivalent
TSN	Type code number
UDC	Urban Driving Cycle; Part 1 of the New European Driving Cycle
UNECE	United Nations Economic Commission for Europe

2. Summary

In this In-Service Conformity test programme a total of 65 vehicles, spread over 5 vehicle types with positive ignition engine (within this 1 vehicle type with ethanol fuel, E85) and 8 vehicle types with compression ignition engine were tested with respect to the exhaust emissions limited by law.

The measurements were carried out in the respective type approval cycle, the "New European Driving Cycle"(NEDC) in accordance with EU Regulation 715/2007/EC (Type I test). In addition to this, measurements according to the upcoming Worldwide Harmonized Light Vehicle Test Procedure (WLTP) was conducted according to the latest version of the existing Procedure Draft and three vehicle types were tested with the Portable Emission Measurement System (PEMS) method on road and in real traffic. During the measurements on the chassis dynamometer, the exhaust emissions were measured and the fuel consumption was calculated from the emissions of the carbon-containing exhaust components. Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured of all vehicles with positive ignition engine. At two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. In addition on two vehicles per type with positive ignition engine, the exhaust emissions at low ambient temperatures (Type VI test) were measured. With the Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars was introduced. With EU Regulation 715/2007/EC the Diagnose of Compression ignition engines becomes more important. During this programme the OBD-data were registered. Additional, some emission relevant failures were simulated to control the function of the OBD system of one vehicle per type. Below, some of the main findings during the 2015 programme.

- 1 positive ignition vehicle failed the SHED test (Type IV)
- 1 compression ignition (of 5) vehicle failed the NOx limit during Type I test
- 2 compression ignition vehicles (of 5) failed the NOx limit during Type I test and 1 of these also failed the limit for Particulate number because of a damaged the filter (DPF).
- 5 compression ignition vehicles (of 5) failed the NOx limit during type I test
- 2 compression ignition vehicles (of 5) failed the NOx limit during Type I test
- 1 compression ignition vehicle (of 5) failed the NOx limit during Type I test

All compression ignition vehicle types tested were fitted with particle filter. One of the compression ignition vehicles tested during this programme exceeded the limit for particle mass and in total 12 for nitric oxides. According to the statistical procedure defined with EU Regulation 715/2007/EC one compression ignition vehicle types did not complied with the requirements for In-Service test. One of the compression ignition vehicles was of Euro 6

During the Type I test on 13 vehicle types the measured and the average fuel consumption (and CO_2) was higher than the fuel consumption declared by the manufacturer for 12 vehicle types. Average for compression ignition vehicles was an increase of 4 percent and for positive ignition vehicles an increase of 6 percent.

Measuring exhaust emissions at idle speed during the Type II test no emission related problems were detected.

On all vehicle types with positive ignition engine no crankcase emissions were emitted into the atmosphere at the Type III test.

During the exhaust emission test at low ambient temperatures (Type VI test), all tested vehicles complied with the limits according to EU Regulation 715/2007/EC.

During this project the OBD-data were registered. In addition some emission relevant defects were simulated to control the function of the OBD system at one of the vehicles per type. All simulated failures were detected by the OBD systems.

To test the vehicles on different test cycles showed the influence of driving behaviour and driving conditions on the exhaust emissions. Dynamic driving, high speed, high engine load and cold start conditions cause an increase of carbon monoxide and hydrocarbon emissions, especially on vehicles with positive ignition engine. The major environmental exposure caused by compression ignition vehicles is nitric oxide and particulate emissions. NO_x was emitted by compression ignition vehicles especially during the WLTC cycle. This is due to the high temperature inside the combustion chamber at high engine load, combined with a surplus of oxygen within the cylinder. It became obvious that dynamic driving with strong accelerations on urban conditions gives the worst fuel consumption. Positive ignition engines suffer from cold start the most. Smoothly running traffic with moderate speed and acceleration gives the lowest fuel consumption.

3. Introduction

Well-functioning transportation is vital for undertakings and citizens. Road transport dominates as it carries about 46 percent of freight and 83 percent of passenger traffic in Europe. The rise of the population causes a rise of the number of passenger cars. **Figure 1** shows the trend for the last 100 years.

In end of 2015 Sweden's population 9,851,017 people. There is an increase of 103,662 people compared with the previous year. Population growth is the biggest ever recorded between two individual years. The main reason for this is a record high immigration. The number of passenger cars in traffic was (December 2015) 4 678 271.

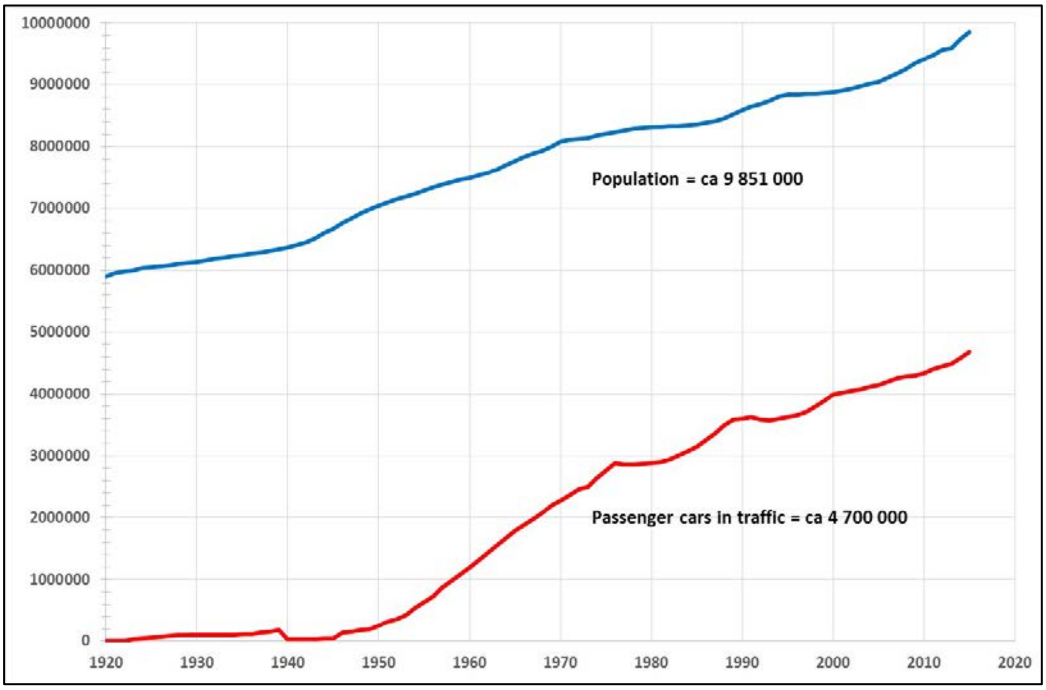

Figure 1*. Population and passenger cars in traffic in Sweden the last 100 years,*

Within this rising number of passenger cars and population the pollution of the air by the emissions gets more and more important. Looking at the last nine years the number of sold passenger cars equipped with a compression ignition engine increases from 20 percent in 2006 up to 58 percent in 2015.

Main changes 2015 compared with 2014 and some comments on the Swedish vehicle fleet.

Number of sold passenger cars	+ 13,5 % (345 053 sold cars)
Percent sold compression ignition vehicles of total	58 % (-2 %)
E85 cars	1239 (- 50 %)
Gas cars	5031 (+ 1,5 %)
Electrical cars	2962 (+140 %)
Hybride cars	13747 (+ 29 %)

Table 1. *Sold passenger cars 2015*

- In addition the use of Ethanol (E85) decreased from the highest use of 20 percent in 2008 down to about close to zero percent in 2015.
- The number of compression ignition vehicles sold is still on a high level.
- The number of hybrid- and or electrical vehicles increase but the total number is still on a low level
- The total number of vehicles in traffic increase steadily from year to year and correlate to the increasing population.

Transport policies aim at ensuring clean, safe and efficient carriage of passengers and goods. Increasing the efficiency and reducing negative effects of road traffic on the environment is a major challenge. Road traffic is still the main source of air pollution from carbon monoxide, hydrocarbons and nitrogen oxides in Europe. In order to counter environmental pollution from motor vehicle emissions, exhaust legislation has been stepwise tightened over the past few decades. There is now an extensive package of measures available to reduce air pollution due to road traffic. This includes both control of new vehicles and test of vehicles in-use. The control of new vehicles comprises type approval, durability test and conformity of production (COP). The control of vehicles in-service includes an on-board diagnosis (OBD) system in the vehicles, the periodic inspection of all vehicles on the road, vehicle manufacturers' In-Service Conformity test, plus enhanced requirements regarding fuel quality. **Table 2** shows various statutory measures taken to reduce exhaust emissions from motor vehicles.

The In-Service Conformity test of vehicles in operation on the roads was introduced in October 1998 with Directive 98/69/EC, the provisions is now included in EU regulation 715/2007/EC. Here privately owned vehicles that have been registered compliant with Directive 98/69/EC or EU Regulation 715/2007/EC are examined after a statistical selection process in a complete test procedure according to the type approval cycle. It is the vehicle manufacturer who is responsible for this test. In addition to the manufacturer's own In-Service Conformity test, some countries in the EU have parallel national programs for In-Service Conformity. On a regular basis, this started in Sweden in 1991, first based on the national emission regulation and later on the EU legislation.

In numerous programmes it has been shown that In-Service Conformity test can reveal type-specific and design-related faults or inadequate maintenance regulations which, after an extended operating period of the vehicle, lead to an inadmissible increase in exhaust emissions.

Swedish Transport Agency (STA) is responsible for type-approval together with other obligations, for motor vehicle emission controls. With that follows the obligation to carry out evaluations of the product performance in-service. The STA has commissioned TÜV Nord (Germany) in collaboration with Ecotraffic (Sweden) to carry out the test programme on light duty vehicles.

The objective of the Swedish test programme is to conduct screening tests on a number of vehicle models, picked out on a spot-check basis, to verify durability in the emission control concept. This is done in close collaboration with the vehicle manufacturers. This enables the manufacturers concerned to rectify any type-specific faults relevant to emissions of the vehicles on the road and serial production and to incorporate knowledge gained from the field monitoring in future developments. By proceeding in this way, this research programme contributes directly to lowering the environmental pollution from emissions caused by road traffic.

Besides In-Service Conformity test it is also a minor objective of the programme to get information of emissions from vehicles during real world driving. These data will be used to update the European emission model HBEFA. HBEFA is used in Sweden for national emission inventories and as input to local air pollution calculations.

To get more information about real world driving the expert group of the European commission for Real Driving Emission on Light Duty Vehicles (RDE-LDV) declared the use of a Portable Emission Measurement System (PEMS) for type approval starting 2017. Up to now the RDE-LDV Group discusses how to proceed such measurements the right way. To update the database and to support the ongoing process three vehicle types of this program where tested with PEMS. The collected data were given to the Joint Research (JRC) Centre of the European Commission.

	New Vehicles			Vehicles on the Road		
	Type Approval Test	**Durability Test**	**Conformity of Production**	**In-Service Conformity test**	**Periodic Exhaust Inspection**	**On-Board Diagnosis**
Aim:	Verification of compliance with statutory specifications by the vehicle type	Verification of compliance with statutory specifications by the vehicle type	Statistical back-up for serial production	Detection of type-specific design-related defects or inadequate maintenance instructions	Detection of high-emission vehicles, servicing condition	Malfunction detection and indications for immediate repair
Area of Responsibility	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Manufacturer	Vehicle Owner	Vehicle Owner
Vehicle Selection	Prototypes	Prototypes or serial vehicles	Random sample from serial production	Random sample of vehicle fleet in the field	All vehicles on the road	All vehicles on the road
Test Interval	One-off	One-off	Sporadic	Regular	Regular	Permanent
Type of Test	Type test	Continuous run (AMA) or fixed deterioration factor	Type test	Type test	Idle test	Actual conditions according to manufacturer's application
Influence on Emission Reduction	Technology used	Durability under laboratory conditions	Technology used and implementation in production	Technology used and implementation in the field	Servicing condition	Durability and servicing condition in actual traffic
Statutory Basis	European Directives governing measures to prevent air pollution from motor vehicle emissions 98/69/EC ; 715/2007/EC			98/69/EC; 715/2007/EC	96/96/EC	98/69/EC; 715/2007/EC

Table 2. *Approaches to the reduction of exhaust emissions from motor vehicles*

4. Project Implementation

4.1. Investigation Programme

Within the framework of this programme a total of 5 vehicle types with positive ignition engine, within this 1 vehicle type with ethanol fuel (flexfuel) on both potential fuels and 8 vehicle types with compression ignition engine were tested with respect to the exhaust emissions limited by EU emission legislation.

The measurements were carried out in the respective type approval cycle, i.e. the "New European Driving Cycle"(NEDC) in accordance with EU Regulation 715/2007/EC. In addition to this, measurements according to the upcoming Worldwide Harmonized Light Vehicle Test Procedure (WLTP) was conducted according to the latest version of the existing Procedure Draft, results were given to the European working group that is responsible for the Correlation exercise between NEDC and WLTP. Three vehicle types were measured on road with PEMS. In this way it was possible to cover the entire operational range relevant to exhaust emissions for vehicles. The different driving cycles are shown in section **4.3**

During the measurements on the chassis dynamometer, the emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X) and carbon dioxide (CO_2) were collected in bags in accordance with the regulations and the integral values were determined. For all vehicles particle mass was determined according to the current regulation. Parallel to this the exhaust emissions were recorded continuously every second (modal measurement). The results of the modal measurements serve as the basis for determining the emission control strategies with which the exhaust emission behaviour can be shown in all relevant traffic situations.

In addition to exhaust emissions, fuel consumption was determined in the respective type approval cycle in accordance with EU Regulation 715/2007/EC. The fuel consumption was calculated from the emissions of the carbon-containing exhaust components (CO_2, CO and HC).

Exhaust emissions at idle speed (Type II test) and crankcase emissions (Type III test) were measured on all vehicles with positive ignition engine.

On two vehicles per type with positive ignition engine the evaporative emissions (Type IV test) were determined. Exhaust emissions at low ambient temperatures (Type VI test) of two vehicles per type with positive ignition engine were measured.

With Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars and light-duty vehicles was introduced. The provisions for the OBD system is developed further in EU Regulation 715/2007/EC. During this programme the OBD-data were registered. In addition some emission relevant failures were simulated to control the function of the OBD system at one vehicle per type.

The test date was agreed upon with the vehicle manufacturer or importer concerned to enable him to be present during the tests. Representatives of the respective vehicle manufacturer were present, having been invited to witness the implementation of the tests.

4.2. Vehicle Selection

It was intended that the selected vehicles should cover as wide a spectrum of manufacturers as possible, while maintaining a representative cross-section of the vehicle types licensed in Sweden. Vehicle types from 10 different manufacturers were investigated in the programme. All selected vehicles were type approved according to EU Regulation 715/2007/EC.

Table 3 shows the exhaust emission limits valid for the type approval test of passenger cars and light duty vehicles. For passenger cars (M1) with a maximum mass bigger than 2,500 kg and light duty trucks (N1) separate limits can be applied according to the reference weight of the vehicle. The "New European Driving Cycle" is described in section 4.3.

Engine	Limit	Vehicle Class *)	Reference Mass (RM) [kg]	CO [mg/km]	HC [mg/km]	NMHC [mg/km]	NO_x [mg/km]	HC+NO_x [mg/km]	PM [mg/km]	PN [#/km]
positive ignition	Euro5	M1 ≤ 2500kg	All	1000	100	-	80	-	-	-
		N1 class I	RM ≤ 1305	1000	100	-	80	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	-	100	-	-	-
		N1 class III	1760 < RM	2270	160	-	110	-	-	-
	Euro6	M1 ≤ 2500kg	All	1000	100	68	60	-	-	-
		N1 class I	RM ≤ 1305	1000	100	68	60	-	-	-
		N1 class II	1305< RM ≤1760	1810	130	90	75	-	-	-
		N1 class III	1760 < RM	2270	160	108	82	-	-	-
compression ignition	Euro5	M1 ≤ 2500kg	All	640	-	-	500	560	50	-
		N1 class I	RM ≤ 1305	640	-	-	500	560	50	-
		N1 class II	1305< RM ≤1760	800	-	-	650	720	70	-
		N1 class III	1760 < RM	950	-	-	780	860	100	-
	Euro6	M1 ≤ 2500kg	All	500	-	-	180	230	4,5	$6,0*10^{11}$
		N1 class I	RM ≤ 1305	500	-	-	180	230	4,5	$6,0*10^{11}$
		N1 class II	1305< RM ≤1760	630	-	-	235	295	4,5	$6,0*10^{11}$
		N1 class III	1760 < RM	740	-	-	280	350	4,5	$6,0*10^{11}$
* N1 limits are also valid for class M vehicles with a maximum mass > 2500kg										

Table 3. *Emission limits for passenger cars and light-duty vehicles, valid for the Type I test (NEDC)*

The vehicle selection was done in cooperation with local dealers to guarantee a good maintenance condition of the vehicles. Further criteria such as kilometre reading and date of first registration were taken into consideration. When the vehicles were taken over for the programme, additional data regarding repairs carried out on the vehicles as well as deviations from the series production condition was noted. The components which are relevant for exhaust emissions were checked for directly recognisable damage. OBD information was read to ensure that no emission relevant fault code was stored.

The following criteria were used as a basis when selecting individual vehicles:

- same type approval for vehicles of one type
- Kilometre reading between 15,000 km (alternatively at least 6 months in traffic) and 100,000 km,
- regular servicing according to manufacturer's advice
- vehicle is unmodified series production model
- no mechanical damage to components

The vehicle types which were investigated are shown in **Table 4** and **Table 5** along with the relevant technical data. All vehicles witch compression ignition engine were equipped with particle filter.

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm^3]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	Suzuki	NZ	Swift	K12B	1242	69	EURO 5	37,453	72,202	Feb11 – Dec12
2	Nissan	J10	Qashquai	MR20	1997	104	EURO 5	39,166	79,632	Jun11 – Jun12
3	Ford	JA8	Fiesta	SNJB	1242	60	EURO 5	29,308	70,584	Jun11 – Oct13
4	Mercedes	245G	A180	270910	1595	90	EURO 6	21,284	42,630	Feb14 – Jan15
5	Volvo	B	V70 (Flexifuel)	B4164T2	1596	132	EURO 5	37,253	84,808	Jul12 – Feb 15

Table 4. *Vehicle Types with positive ignition engine*

Type No.	Manufacturer	Type	Trade name	Engine type	Engine capacity [cm^3]	Power [kW]	Emission approval	Mileage min [km]	Mileage max [km]	Registration
1	Audi	AU	A3	CRKB	1598	81	EURO 5	16,680	51,236	Dec13 – Dec13
2	Toyota	T27	Avensis	IAD-FTV	1998	91	EURO 6	23,311	57,416	May12 – Feb13
3	Volvo	F	V60	D4162T	1560	84	EURO 5	22,159	31,706	Oct13 – Dec14
4	Volkswagen	7J0	T5	CAA	1968	103	EURO 5	27,620	50,773	Jun13 – Jun13
5	Mazda	GH	6	SH	2191	129	EURO 6	18,811	33,562	May13 – Dec14
6	Peugeot	8	508	9H05	1560	82	EURO 5	26,615	69,011	Aug11 – Apr12
7	Ford	WA6	S-Max	TXWA	1997	120	EURO 5	35,604	67,650	May11 – Jun13
8	Volkswagen	5N	Tiguan	CFF	1968	103	EURO 5	34,310	62,508	Apr12 – Feb15

Table 5. *Vehicle Types with compression ignition engine*

4.3. Implementation of Tests

In **Table 6** the application of tests for type approval of passenger cars and light duty vehicles is illustrated.

Test	Description	Positive Ignition Vehicles	Compression Ignition Vehicles
Type I	tailpipe emissions after cold start	yes	yes
Type II	carbon monoxide emissions at idling speed	yes	-
Type III	emission of crankcase gases	yes	-
Type IV	evaporative emissions	yes	-
Type V	durability of anti-pollution control devices	yes	yes
Type VI	low ambient temperature tailpipe emissions after a cold start	yes	-
OBD	On Board Diagnosis	yes	yes

Table 6. *Application of tests for type approval*

Within the framework of the programme 13 vehicle types were tested. The investigations were implemented with reference to EU Regulation 715/2007/EC. In order to obtain a reliable assessment if type-specific defects are present on a vehicle type, initially five vehicles per type were measured with respect to exhaust emissions.

The vehicles were selected in cooperation with authorized dealers to be sure that the vehicles were maintained according to the manufacturer's requirements. All vehicles were checked and the OBD information was read to ensure that no emission relevant fault code was detected.

After the vehicles had been received at the laboratory, a check was made as to whether the specified maintenance intervals had been observed and that the vehicles were in a proper condition. Proof was provided by means of the service record manual. Before commencement of the measurements on the chassis dynamometer, the vehicles were checked with respect to the tightness of the exhaust system.

For dynamometer setting the same inertia weight and coast down values were chosen as for the type approval test. A deterioration factor was not used for evaluating the Type I test results. The vehicle types were assessed in accordance with EU Regulation 715/2007/EC.

The vehicles were tested in a measuring programme which not only includes the tests applied for type approval, but also covers other test cycles like WLTP to determine exhaust emission factors. **Table 7** and **Figure 2** gives a simplified illustration of the programme. It does not show the different tests in the order conducted during the programme.

The WLTP was driven according the version of the WLTP GTR in the beginning of the test programme to implement an additional conditioning of the vehicles before starting the tests according to the directive. On the afternoon of the day before running the Type I tests, all vehicles were conditioned (NEDC for vehicles with positive ignition, 3 Extra Urban Driving Cycles (EUDC) for vehicles with compression ignition).

Type II and III tests on vehicles with positive ignition engine were carried out immediately after the Type I test. The OBD check was done at the end of the test procedure to make sure that the simulation of emission relevant failures could not affect the results of the other tests. **Table 7** displays the procedure of the different tests during the programme.

Step	Item	Positive Ignition Type	Compression Ignition Type
1	WLTP (according GTR)	3 vehicles per type	3 vehicles per type
2	Conditioning	5 vehicles per type (NEDC)	5 vehicles per type (3 x EUDC)
3	Type I test	5 vehicles per type	5 vehicles per type
6	Type II test	5 vehicles per type	not relevant
7	Type III test	5 vehicles per type	not relevant
8	Type IV test	2 vehicles per type	not relevant
9	Type VI test	2 vehicles per type (incl. Conditioning)	not relevant
10	OBD check	1 vehicle per type	1 vehicle per type
11	PEMS	3 vehicles per 2 types	3 vehicles per 1 type

Table 7. *Test programme*

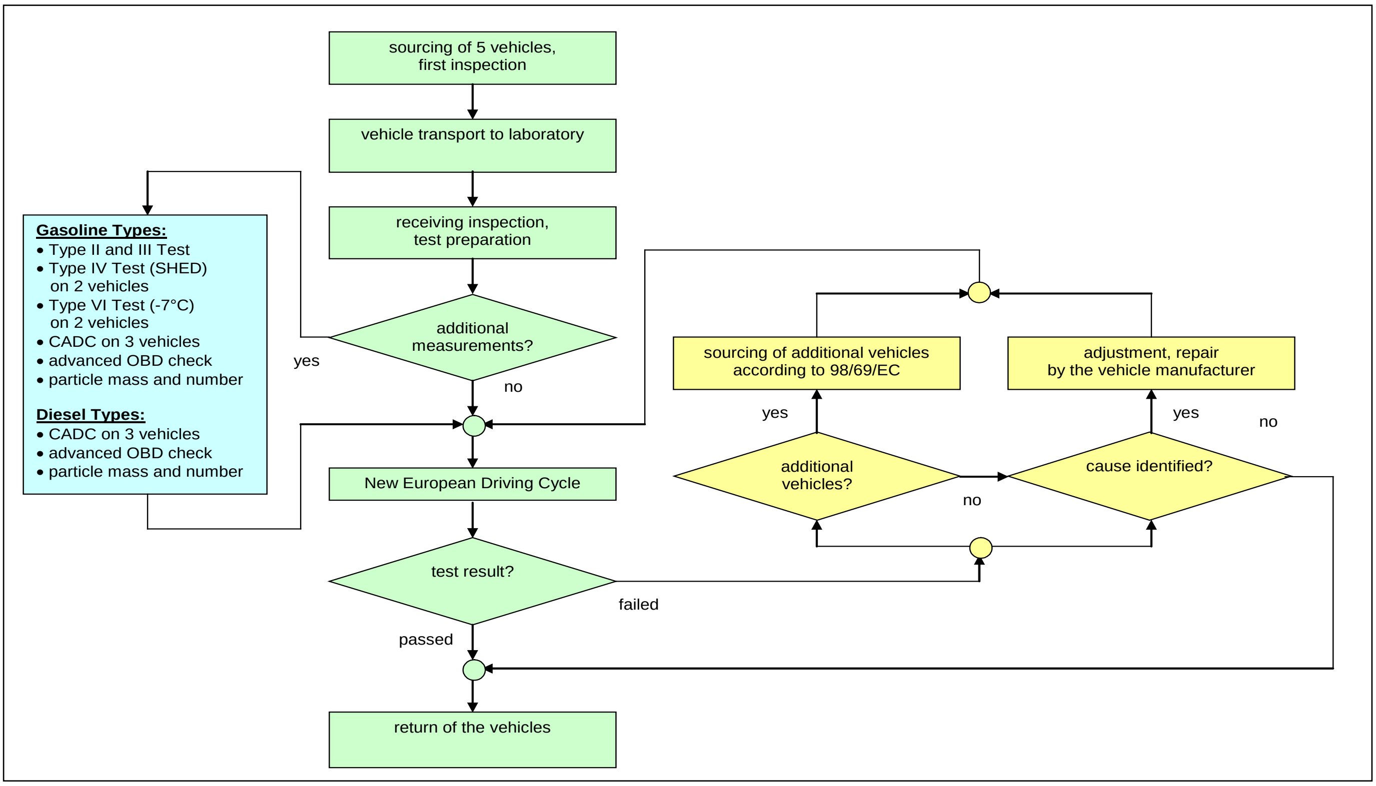

Figure 2 *Simplified illustration of the In-Service Conformity Test programme*

4.4. New European Driving Cycle (NEDC)

After conditioning the vehicle for at least 6 hours at an ambient temperature of 20 °C up to 30 °C the New European Driving Cycle (NEDC) begins with a cold start. The Urban Driving Cycle (UDC) has duration of 780 seconds, a driving distance of 4.1 km, an average speed of 19 km/h and a maximum velocity of 50 km/h. It is followed by an Extra Urban Driving Cycle (EUDC) with a duration of 400 seconds, a driving distance of 6.9

km, an average speed of 62.6 km/h and a maximum velocity of 120 km/h. Exhaust emissions of both UDC and EUDC are combined to get a total test result.

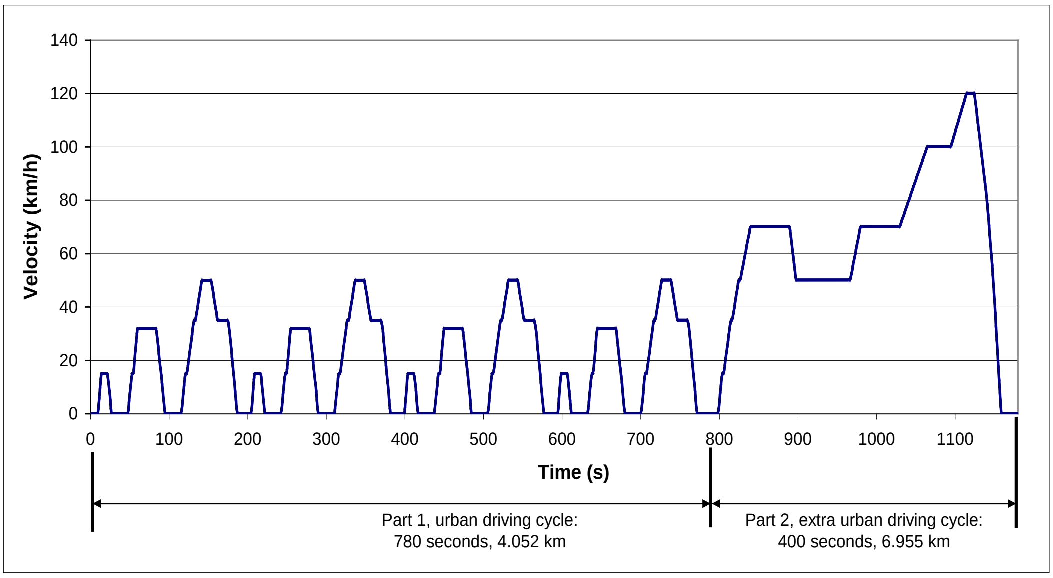

Figure 3. *New European Driving Cycle*

4.5. Worldwide Light Vehicle Test Cycle (WLTC)

The test cycle part of WLTP is the WLTC and consists of four phases. The predominant WLTC cycle in EU is the class 3.

- Phase Low, duration 589 seconds
- Phase Medium, duration 433 seconds
- Phase High, duration 455 seconds
- Phase Extra High, duration 323 seconds

The following figures show the different Phases.

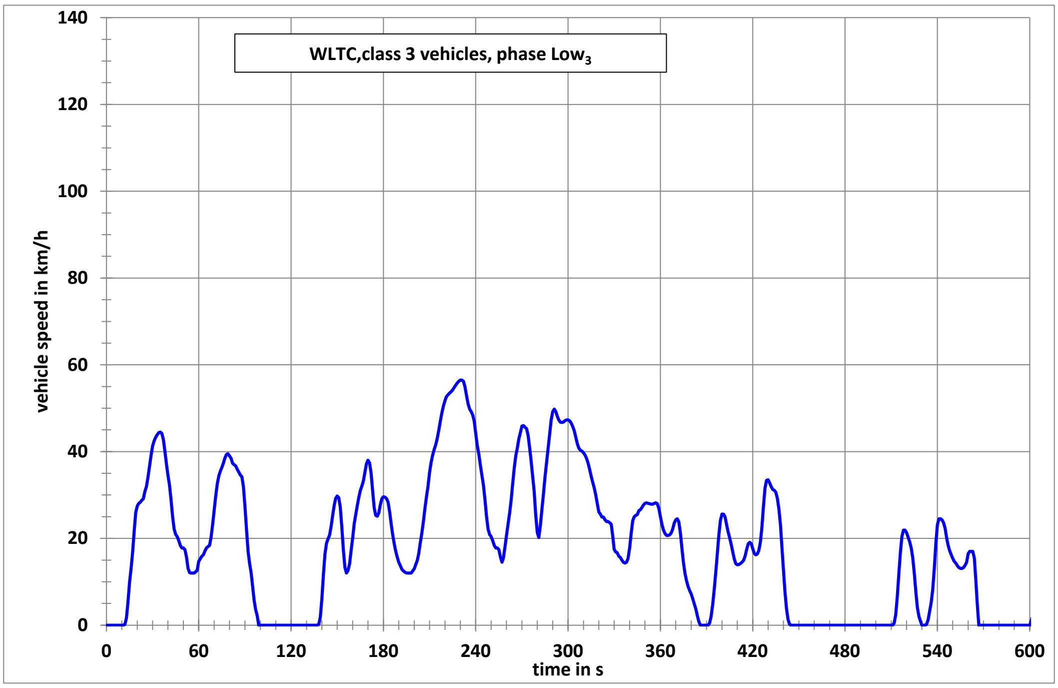

Figure 4. Phase Low

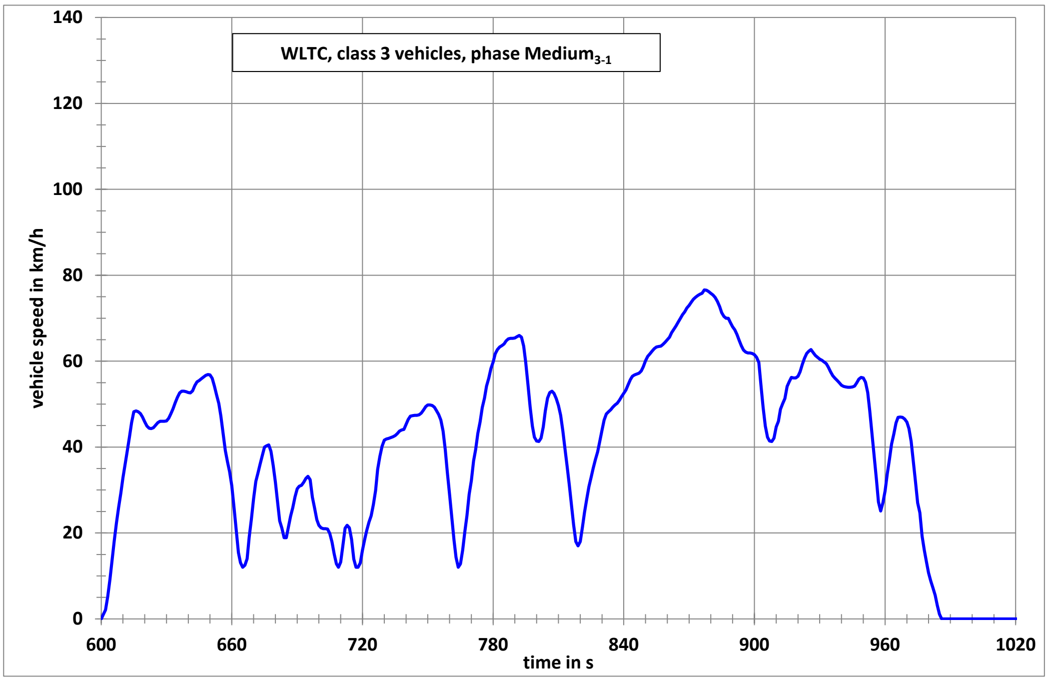

Figure 5. *Phase Medium*

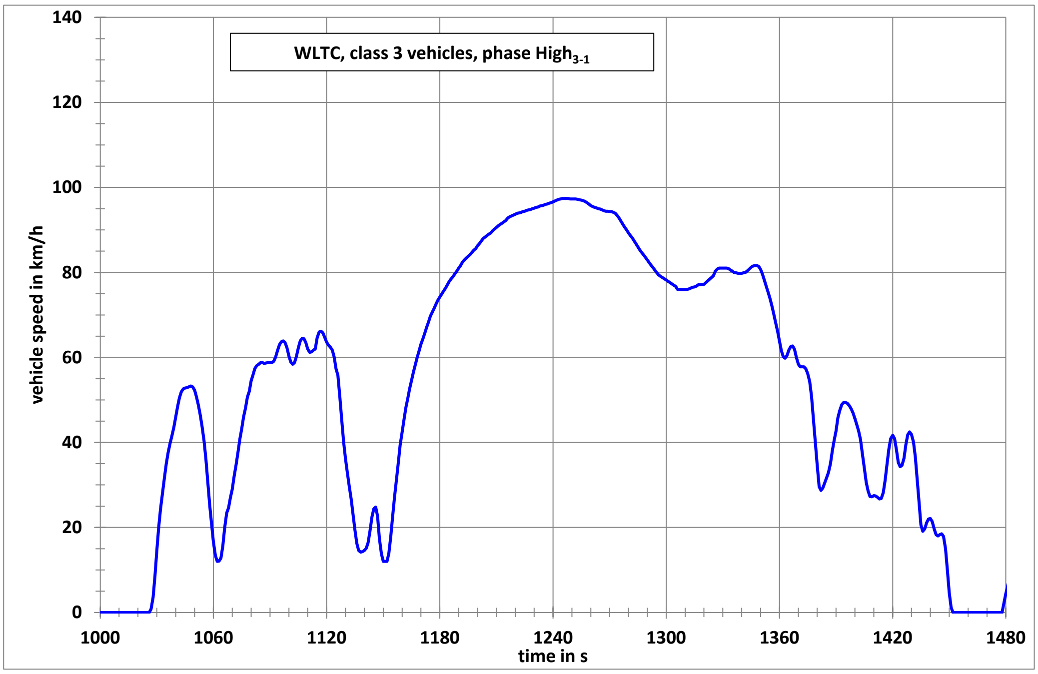

Figure 6. *Phase High*

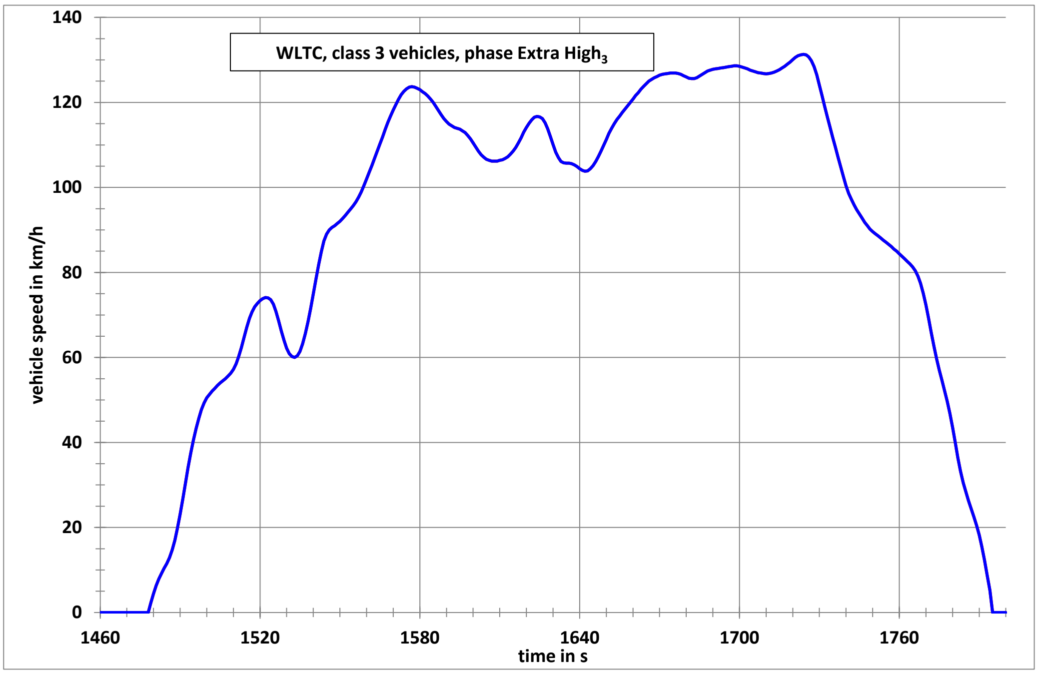

Figure 7. *Phase Extra High*

A comparison of the sub-cycles of NEDC and WLTC is given in **Table 8.** The average speed of UDC is comparable to WLTC LOW. The same is valid for EUDC and WLTC HIGH. However the WLTC cycles are much more dynamic as can be seen from the Relative Positive Acceleration (RPA). The gear shifting points are determined in accordance with the vehicle's weight, engine power and engine revolutions.

Driving cycle	NEDC		WLTC – class 3			
	UDC	EUDC	LOW	MEDIUM	HIGH	EXT-HIGH
Distance [km]	4.1	7.0	3,1	4,8	7,2	8,3
Average Speed [km/h]	19	63	19	40	57	92
RPA [m/s^2]	0.13	0.09	1,5	1,6	1,6	1,6

***Table 8**. Comparison of driving cycles*

Gaseous emissions in all driving cycles were measured integrally and in parallel continuously every second (modal measurement). The results of the modal measurements may serve as the basis for determining the exhaust emission behaviour in all relevant traffic situations.

4.6. Portable Emission Measurement System (PEMS)

During the measurements on road the Measurement System is equipped in the car. The emissions are measured second by second at the end of exhaust pipe.
In addition to the Gaseous emissions (THC, NOx, CO, CO_2) the particulate mass was measured by a soot sensor. Figure 4.6 shows the most important information about the driving route used.

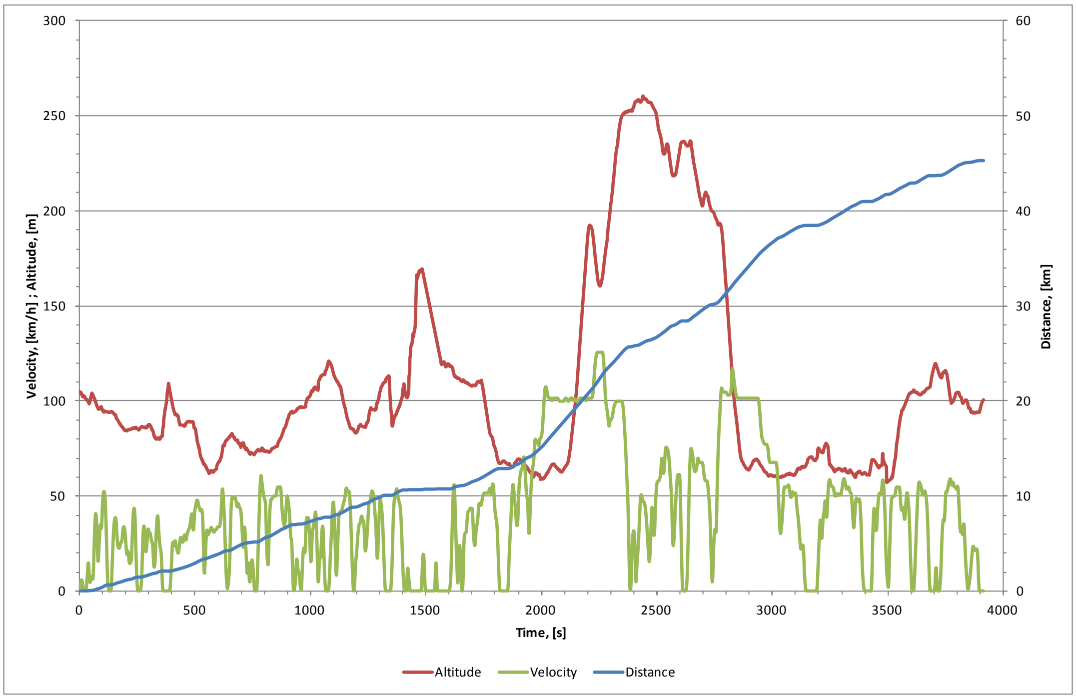

***Figure 8.** PEMS route*

The results of the PEMS measurements carried out within this program were given to the Joint Research Centre of the European Commission. PEMS results from tests in the 2015 programme is available in a separate TÜV NORD report.

5. Presentation of Results

5.1. Exhaust Emissions (Type I test)

In the following sections the values for exhaust emissions and fuel consumption of the various vehicles in the respective approval cycle are examined. **Figure 9** to **Figure 11** give examples for the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of a Euro 5 vehicle with positive ignition engine during Type I test.

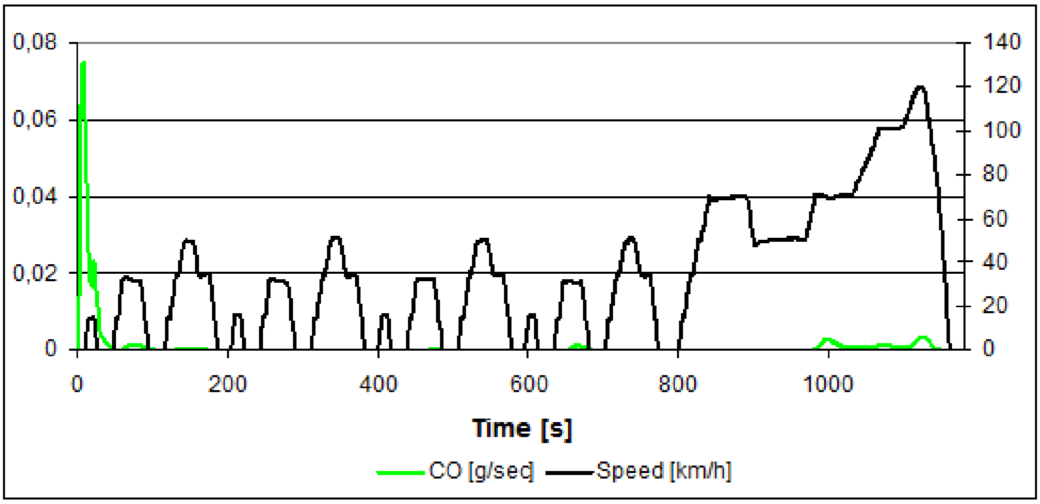

Figure 9. *CO emitted by a positive ignition vehicle during NEDC*

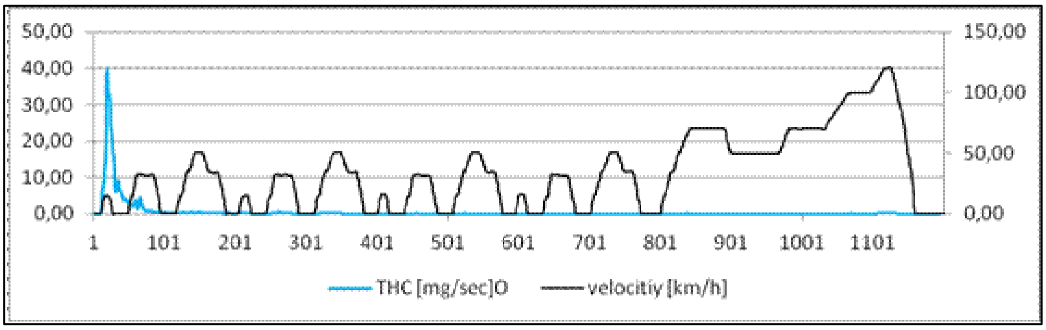

Figure 10. *THC emitted by a positive ignition vehicle during NEDC*

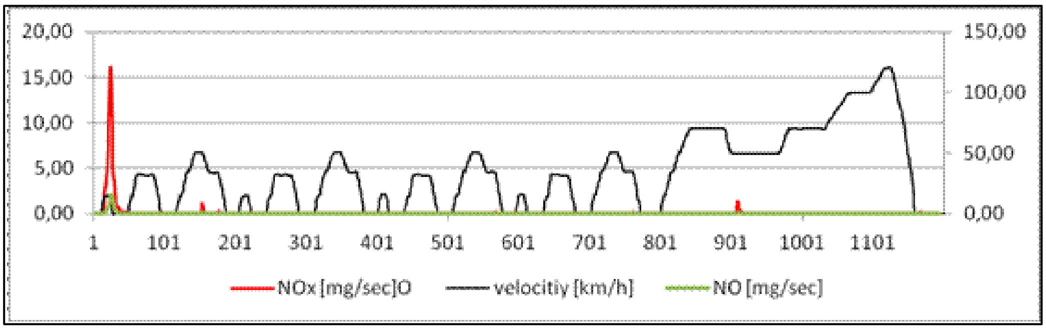

Figure 11. *NOx and NO emitted by a positive ignition vehicle during NEDC*

The major fraction of the CO, the THC and NOx emissions occurs at cold start conditions in the beginning of the driving cycle. As soon as the catalyst has reached its light off temperature of about 250°C carbon monoxide, hydrocarbons and nitric oxides are converted to carbon dioxide, water vapour and nitrogen.

Figure 12 to Figure 14 show the carbon monoxide emissions, the total hydro carbon emissions and nitric oxide emissions of a Euro 5 vehicle with compression ignition engine during Type I test.

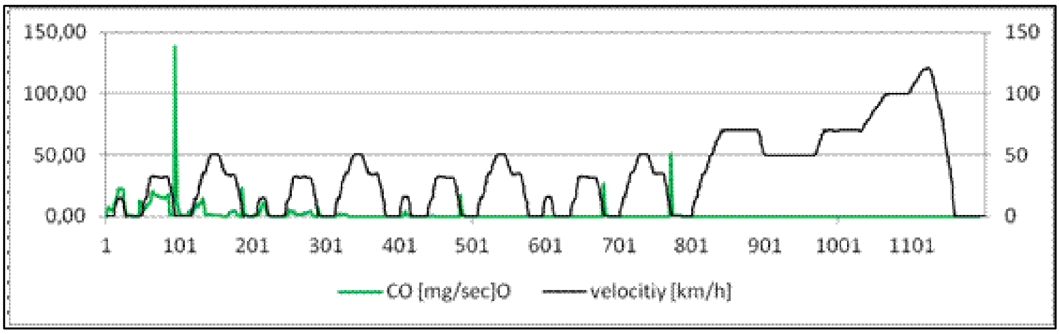

Figure 12. *CO emitted by a compression ignition vehicle during NEDC*

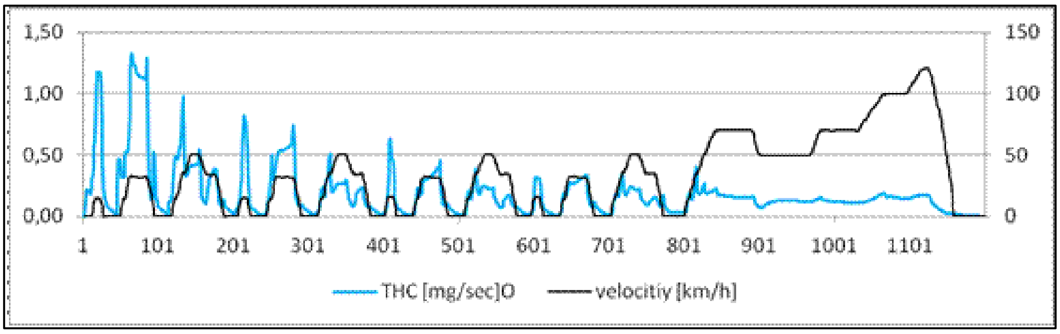

Figure 13. *THC emitted by a compression ignition vehicle during NEDC*

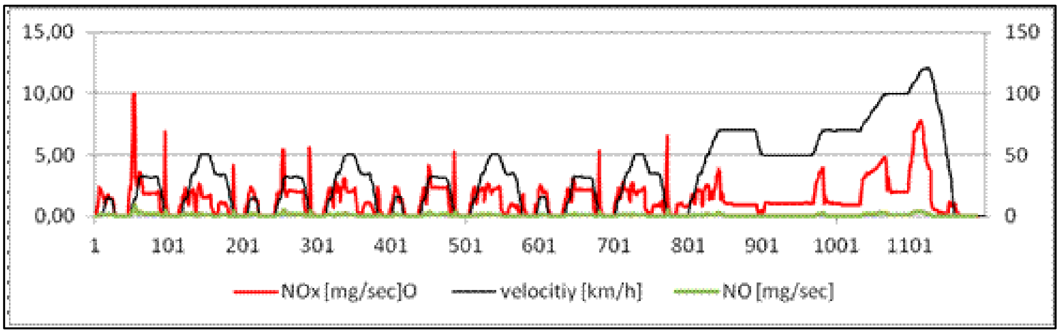

Figure 14*. NOx and NO emitted by a compression ignition vehicle during NEDC*

Carbon monoxide and total hydro carbon emissions of compression ignition vehicles show a graph similar to positive ignition vehicles on a lower level. Due to cold start the major fraction of CO and THC are emitted during the first minutes of the test. As soon as the catalyst has reached its light off temperature, carbon monoxide and hydro carbons are oxidised. Because of the different combustion process, compression ignition engines generate higher nitric oxide emissions than positive ignition engines. High temperatures and a surplus of oxygen in the combustion chamber cause nitric oxide emissions. These conditions are found especially during accelerations. Due to an oxygen surplus within the exhaust gas these nitric oxides cannot be converted by a three-way catalytic converter on compression ignition cars.

In **Table 9** average of the measured exhaust emissions for the different vehicle categories are compared to the type approval limits. The average emissions of all types tested complied with the limits given by the regulation.

Category	**Emission class**	**Cycle**	**Average Exhaust Emissions**						
			CO **[mg/km]**	**HC** **[mg/km]**	**NMHC** **[mg/km]**	**NO_x** **[mg/km]**	**$HC+NO_x$** **[mg/km]**	**PM [mg/km]**	**PN [#/km]**
Compression ignition	Euro 6	UDC	911	37,7	25,7	61	98,7	**-**	**-**
	Euro 6	EUDC	119	18,6	8,7	30	48,6	**-**	**-**
	Euro 6	NEDC	409	25,6	14,9	41,4	67,0	0,16	3,89x10^{10}
Limit	**Euro 6**	**NEDC**	**500**	**-**	**-**	**80**	**170**	**4,5**	**6,0x10^{11}**
Positive ignition	Euro 6	UDC	321	73,3	64,7	19,1	92,4	**-**	**-**
	Euro 6	EUDC	64	1,0	0,7	1,1	2,1	**-**	**-**
	Euro 6	NEDC	158	27,7	24,2	7,8	35,5	0,30	4,81x10^{11}
Limit	**Euro 6**	**NEDC**	**1000**	**100**	**68**	**60**	**-**	**4,5**	
Positive ignition	Euro 5	UDC	809	101	93,8	25,3	126	**-**	**-**
	Euro 5	EUDC	70	3,2	2,7	9,0	12,2	**-**	**-**
	Euro 5	NEDC	341	39,3	36,1	15,0	54,3	0,55	7,36x10^{11}
Limit	**Euro 5**	**NEDC**	**1000**	**100**	**68**	**60**	**-**	**4,5**	**-**
Compression ignition	Euro 5	UDC	228	13,0	6,8	201	314	**-**	**-**
	Euro 5	EUDC	8,7	2,4	0,4	139	141	**-**	**-**
	Euro 5	NEDC	89	6,3	2,8	162	168	0,23	4,85x10^{11}
Limit	**Euro 5**	**NEDC**	**500**	**-**	**-**	**180**	**230**	**4,5**	**6,0x10^{11}**

Table 9. *Average exhaust emissions during Type I test*

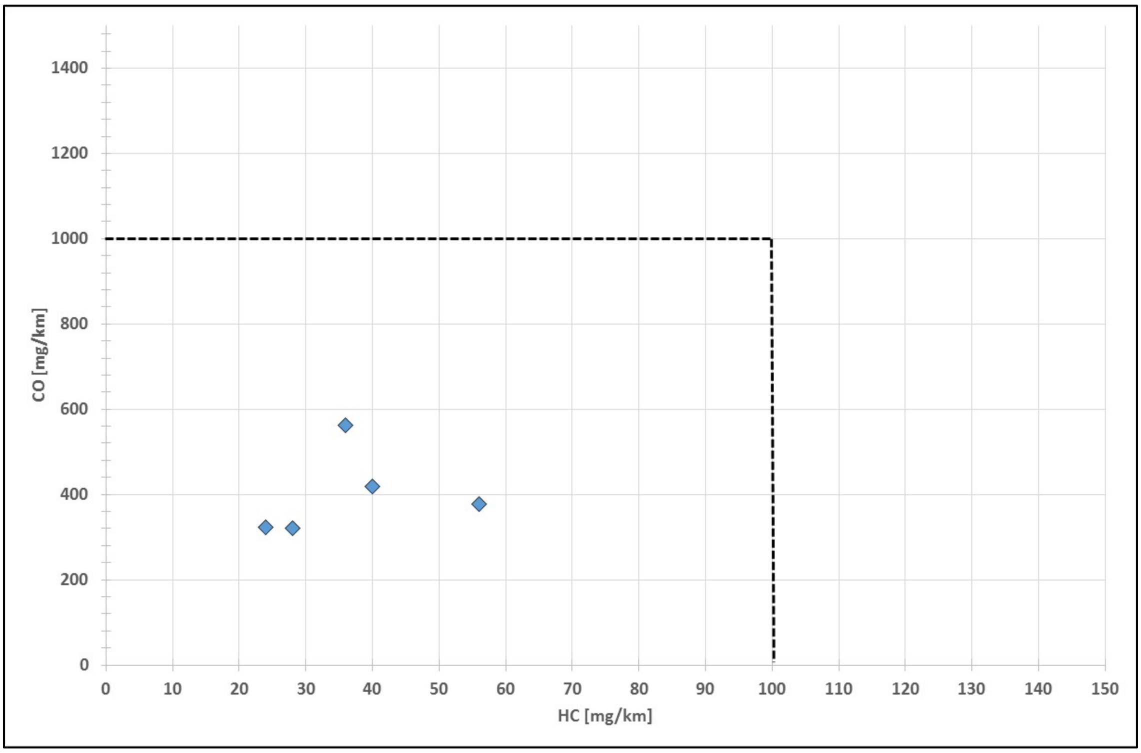

Figure 15. *Average CO and HC emissions of vehicle types with positive ignition during Type I test*

Figure 15 presents the carbon monoxide emissions and the hydrocarbon emissions from vehicle types with positive ignition during Type I test. None of the positive ignition vehicle types tested exceeded the Euro 5 limits for carbon monoxide and hydro carbons during Type I test.

Particle mass emissions and nitric oxide emissions from vehicle types with positive ignition during Type I test are shown in **Figure 16.**

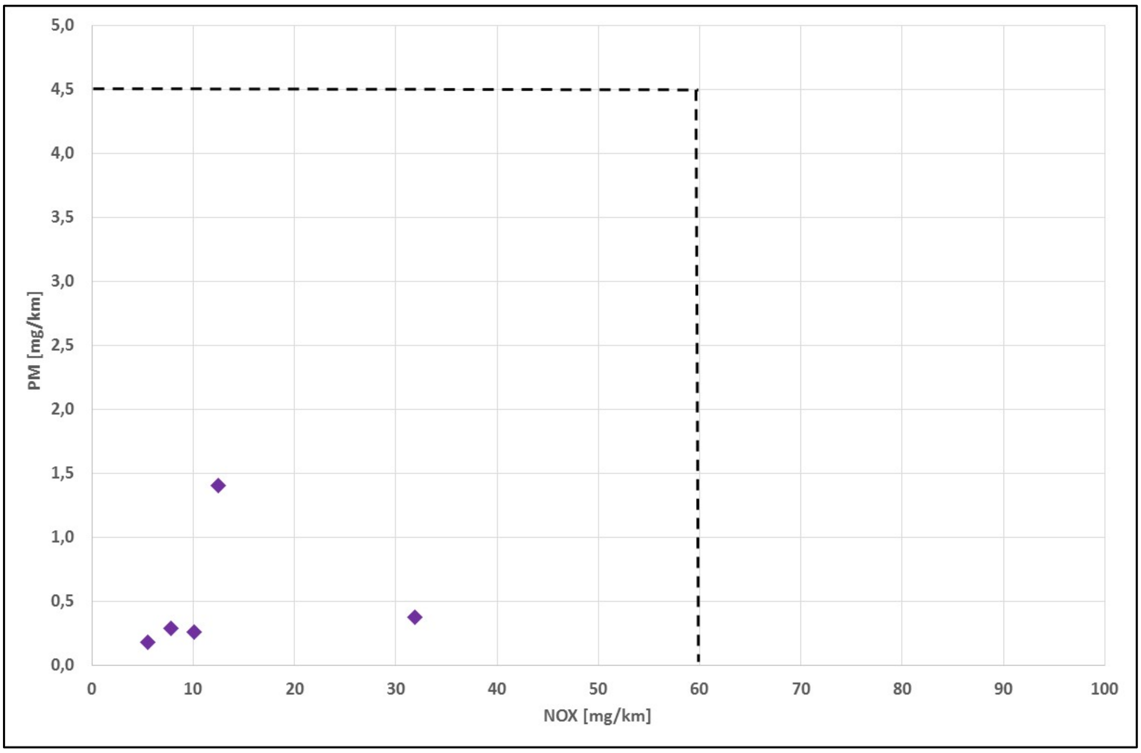

Figure 16. *Average PM and NOx emissions of vehicles with positive ignition during Type I test*

All five tested positive ignition vehicle types complied with the Euro 5 limits during Type I test and fulfilled the requirements for In-Service test according to the statistical procedure defined with EU Regulation 715/2007/EC.

Figure 17 shows particle mass and nitric oxides emitted by one Euro 6 (green) and seven Euro 5 vehicle types with compression ignition engine and particle filter during the Type I test.

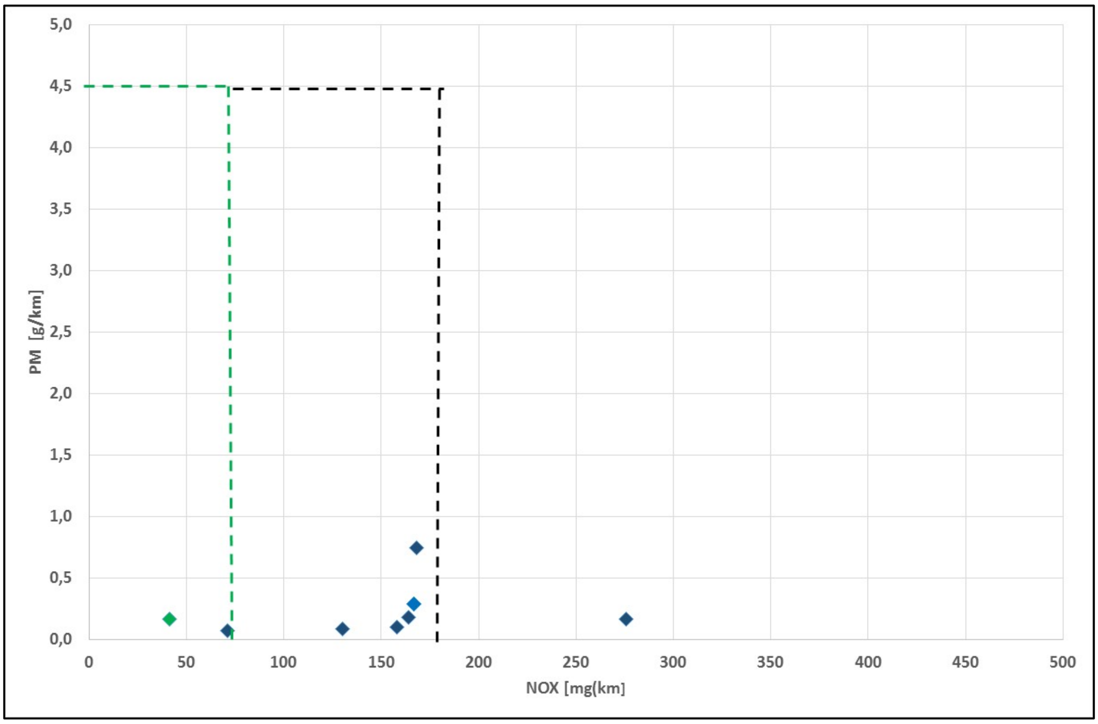

Figure 17. *Average particle mass and NOx emissions of Euro 5 and 6 vehicles with compression ignition and particle filter during Type I test*

All tested vehicle types with compression ignition were equipped with a periodically regenerating particulate trap. During type approval a factor (Ki) is used to consider the emissions during filter regeneration. The values given in this report do not consider the Ki factor. But also considering the emission during filter regeneration and the Ki factor all Euro 5 and Euro 6 compression ignition vehicle types with particle filter complied with the limit for particulate mass given in EU Regulation 715/2007/EC. One of the tested vehicle types did not passed the limit for NO_X-emissions.

5.2. Categorisation of Carbon Dioxide Emissions and Fuel Consumption

Carbon dioxide is an important greenhouse gas because it transmits sunlight and strongly absorbs the infrared radiation reflected by earth. Combustion of fossil fuels increases the concentration of carbon dioxide in the atmosphere. Road traffic is a major source for man-made carbon dioxide emissions. Traffic of passenger cars contributes to 12 percent of man-made CO_2 in Europe, according to 2004, EU-25 figures from the European Commission.

Determination of CO_2 emission and fuel consumption is part of a type approval according to EU regulation 715/2007/EC. These values are therefore a part of the type approval. However, there are at the moment no limit values in the type approval regulation. The CO_2 and consumption declarations are for consumer information and in many EU countries used as a basis for vehicle related taxes. The Regulation requires the values to be contained in a document that is supplied to the owner by the manufacturer when the vehicle is purchased. If the CO_2 and fuel consumption values are considerably exceeded, the buyer could apply warranty claims in the legal sense.

There is a requirement on the manufacturer on average CO_2 emissions from all vehicles sold during a year. From the year 2015 the average CO_2 emissions shall not exceed the limit value of 130 g/km. If there is an exceedance the manufacturer have to pay a fine for every gram exceeding the limit. From 2020 the limit value is 95 g/km.

The CO_2 emissions are measured in the "New European Driving Cycle". The fuel consumption is calculated using the measured CO_2 emissions and the other carbon-containing emissions (CO and HC). The test vehicle must be presented in good mechanical condition. For type approval it must be run-in and it must have been driven for at least 3,000 km, but for less than 15,000 km.

In **Figure 18** the average fuel consumption determined during the Type I test for the tested vehicle types is compared to the value declared by the manufacturers.

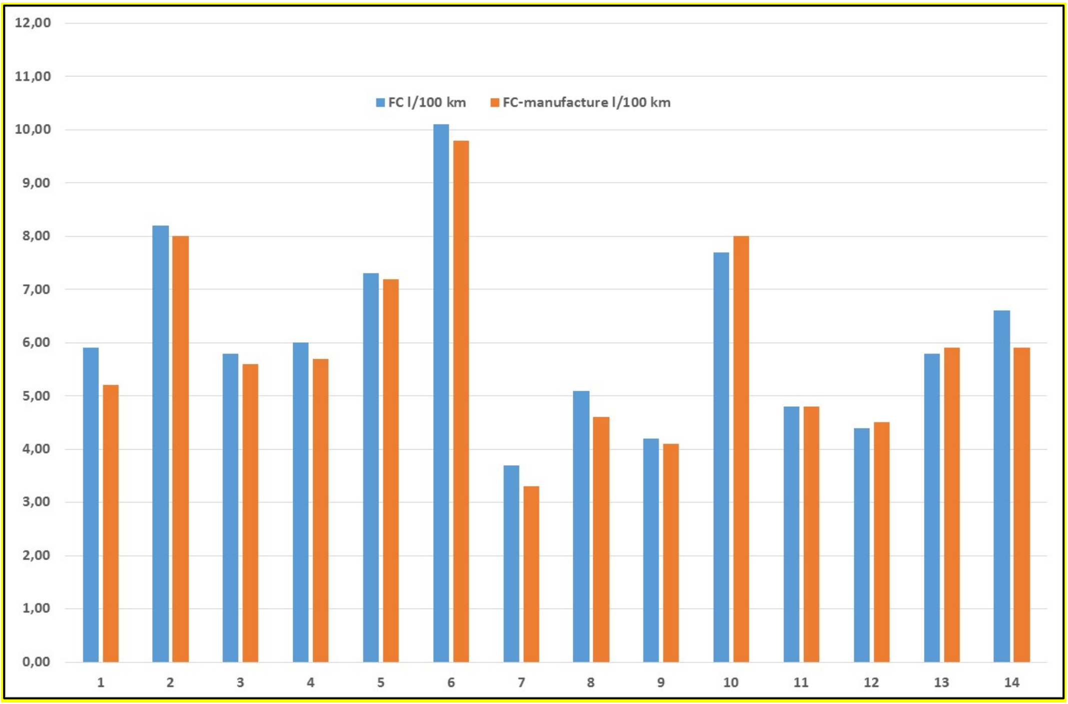

Figure 18. *Average fuel consumption during Type I test for the different vehicle types*

During the Type I test on 14 vehicles the measured average fuel consumption was higher than the fuel consumption declared by the manufacturer for 10 vehicle types. For one vehicle type the deviation on fuel consumption from the values given by the manufacturer was 11,8 percent. For three vehicle types the determined average fuel consumption was lower than the declaration by the manufacturer.

The average CO_2 emissions determined during the Type I test for the tested vehicle types compared to the values declared by the manufacturers are given in **Figure 19** and **Figure 20**.

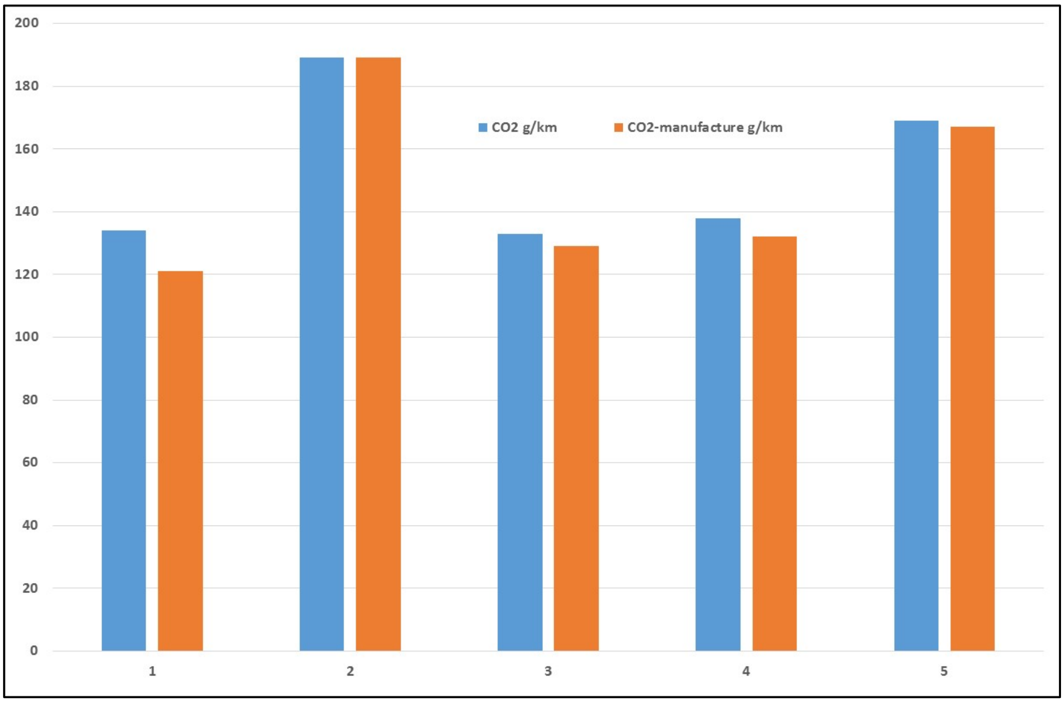

Figure 19. *Average CO_2 emissions during Type I test for the different vehicle types with positive ignition engine*

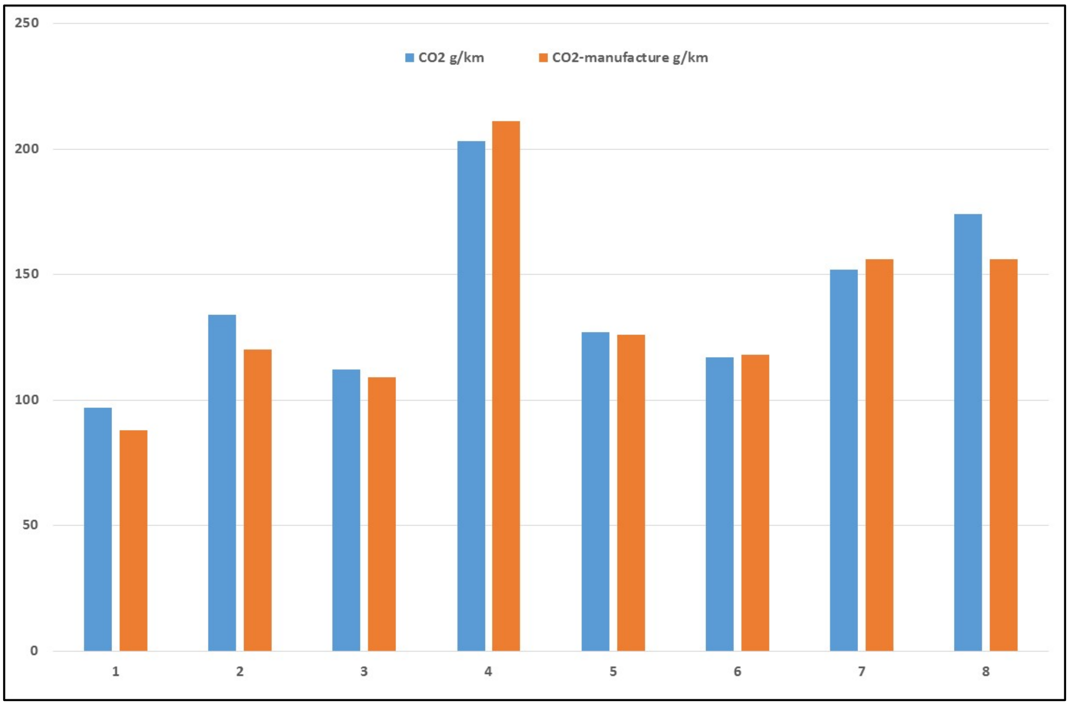

Figure 20. *Average CO_2 emissions during Type I test for the different vehicle types with compression ignition engine*

Figure 21 shows the relative deviation of the CO_2 emissions measured during Type I test to the value declared by the manufacturers.

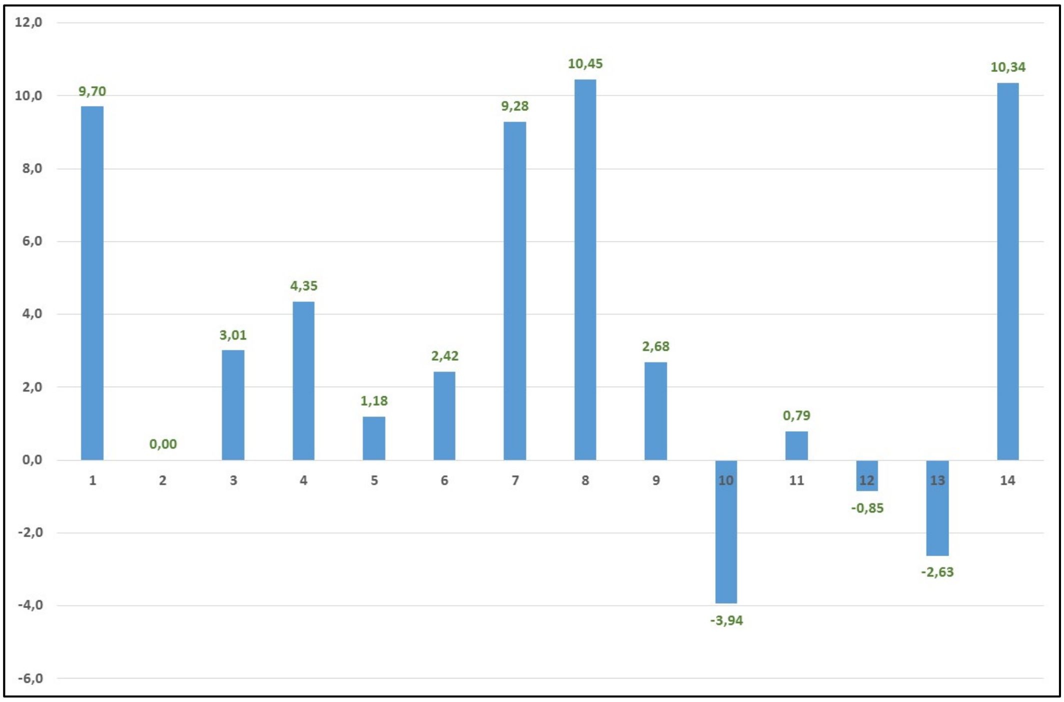

Figure 21. *Relative deviation in percent of the CO_2 emissions to the values declared by the manufacturer during Type I test for the tested vehicle types*

For 4 vehicle types the average CO_2 emissions measured during Type I test were higher than 5 percent above the declaration by the manufacturer. Three vehicle types showed lower CO_2 emissions than declared by the manufacturers.

5.3. Idle Test (Type II test)

On vehicle types with positive ignition engine exhaust gas concentrations are measured at idle speed. For this test the engine must be warmed up. The exhaust emissions measured at idle speed and at about 2,500 rpm are displayed in**Table 10**. The lambda value is calculated using the concentrations of CO, HC, CO_2 and O_2.

	Idle				
	CO [%vol.]	**HC [ppm]**	**CO_2 [%vol.]**	**O_2 [%vol.]**	**λ**
Average Eu6	0,004	0,40	14,92	0,042	1,002
Average Eu5	0,024	2,55	15,12	0,033	1,000
Limits	3.5	-	-		-
	High idle (ca. 2,500 rpm)				
	CO [%vol.]	**HC [ppm]**	**CO_2 [%vol.]**	**O_2 [%vol.]**	**Λ**
Average Eu6	0,010	0,00	14,96	0,016	1,000
Average Eu5	0,048	4,50	15,03	0,047	1,000
Limits	-	-	-		-

Table 10. *Average exhaust emissions during Type II test*

During the Type II test no emission related problems were detected on the vehicles with positive ignition engine.

The Type II test is not relevant for vehicles with compression ignition engine.

5.4. Crankcase Emissions (Type III test)

Exhaust gases passing by the piston rings could cause environmental pollution. Therefore vehicle types with positive ignition engine are equipped with a crankcase ventilation system. The crankcase gases are routed to the intake manifold and are combusted in the engine. The crankcase ventilation system is tested by measuring the pressure within the system at idle speed and at 50 km/h on the dynamometer with two different load settings. The pressure measured in the crankcase may not exceed the atmospheric pressure at different load conditions.

No crankcase emissions were emitted into the atmosphere at the Type III test on all tested vehicle types with positive ignition engine.

Measuring the crankcase emissions is not relevant for vehicles with compression ignition engine.

5.5. Evaporative Emissions (Type IV test)

If the petrol located in the fuel system is heated up, hydrocarbons evaporate. These vapours escaping into the environment cause considerable pollution. For this reason, modern vehicles with positive ignition engine are equipped with a system for retaining such fuel vapours.

For type approval test, in addition to exhaust emissions in the type I test, the amount of evaporative hydrocarbon emissions escaping mainly from the vehicle fuel system is measured. For this Type IV test a Sealed Housing for Evaporative Emissions Determination (SHED) is used. The Type IV test is designed to determine hydrocarbon evaporative emissions caused by hot soaks during parking and by diurnal temperatures variation. The measurement of evaporative emissions according to EU Regulation 715/2007/EC includes three phases:

- test preparation including a driving cycle
- hot soak loss determination
- diurnal loss determination

For measuring the hot soak emissions, the test vehicle is placed in a SHED for one hour directly after having finished a driving cycle. During the diurnal test the vehicle is placed in the SHED for 24 hours to determine the fuel-system and tank ventilation losses. The vehicle is exposed to an ambient temperature cycle which simulates the temperature profile for a summer day while the hydrocarbons released are measured. In this way, hydrocarbon emissions due to permeation and micro-leaks in the whole fuel system are considered. The results of the hot soak test and of the diurnal test are summated to a total result. The statutory limit value for the total evaporative emissions is 2 g hydrocarbons per test.

Figure 22 gives a detailed outline of the Type IV test procedure according EU Regulation715/2007/EC. During this programme the vehicles were refilled with reference fuel and driven within the Worldwide Harmonized Light Vehicles Test Cycle (WLTC) before starting the SHED-procedure. On all tested vehicles the washer fluid canister was drained, purged and refilled with clear water.

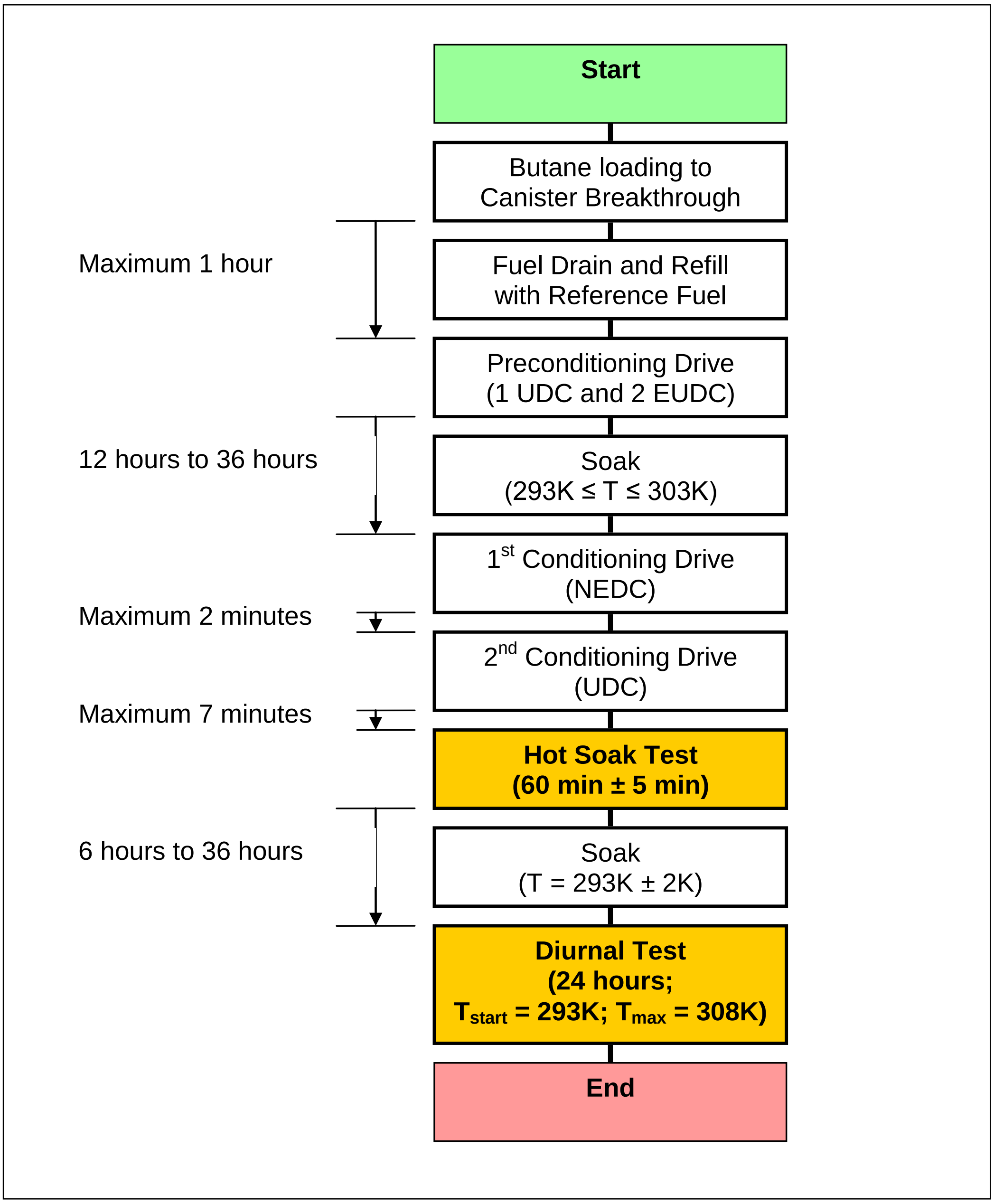

Figure 22. *Type IV test procedure*

During this In-Service Conformity test programme, measurement of the evaporative emissions was performed on two vehicles per type with positive ignition engine in addition to the exhaust emission measurement. The results of these measurements are summarised in **Figure 23**.

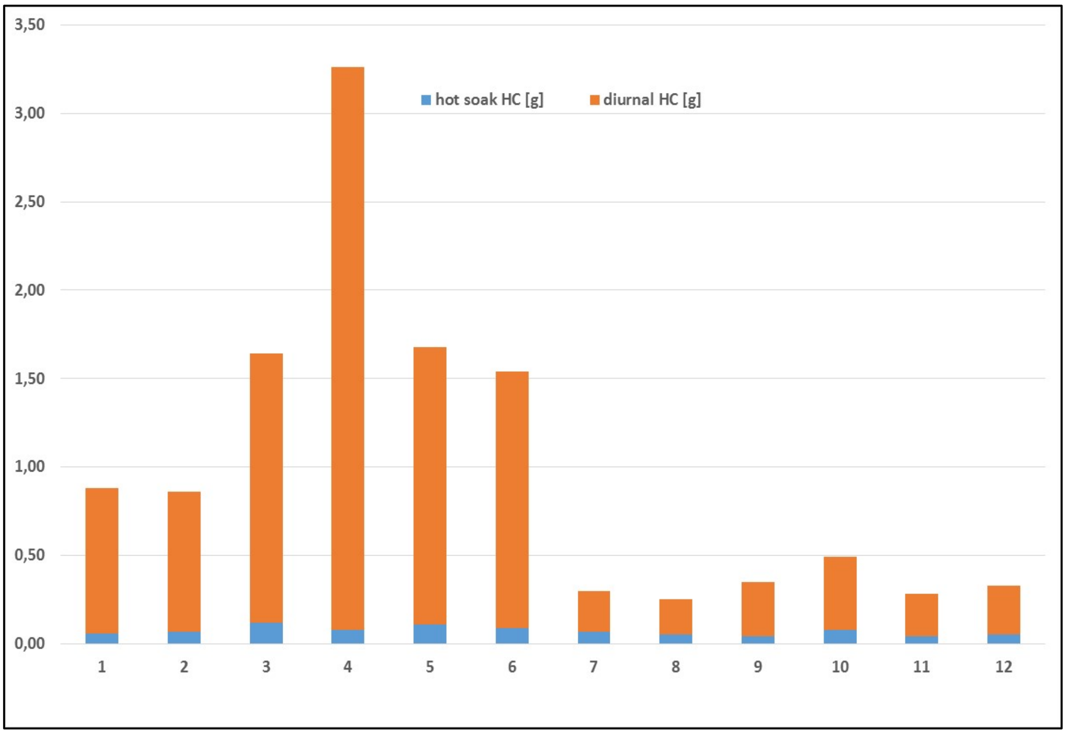

Figure 23. *Evaporative emissions*

One of the 12 tested vehicles exceeded the limit for evaporative emissions according to EU Regulation 715/2007/EC.

Vehicle No.	**Evaporative emissions [g HC]**		
	Hot Soak	Diurnal	Total
1	0,06	0,82	0,88
2	0,07	0,79	0,86
3	0,12	1,52	1,64
4	0,08	3,18	3,26
5	0,11	1,57	1,68
6	0,09	1,45	1,54
7	0,07	0,23	0,30
8	0,05	0,20	0,25
9	0,04	0,31	0,35
10	0,08	0,41	0,49
11	0,04	0,24	0,28
12	0,05	0,28	0,33
Average			
	0,07	**0,92**	**0,99**
Limit			
	-	**-**	**2.00**

Table 11. *Evaporative emissions*

The results presented in **Table 11** show that evaporative emissions during the diurnal test generate the major fraction of the total result.

5.6. Emissions at low Temperatures (Type VI test)

Directive 98/69/EC introduced an exhaust emission test at low ambient temperatures for vehicles with positive ignition engine. Also in EU Regulation 715/2007/EC the test at low temperature is mandatory. The test includes a cold start at -7°C and the urban part of the NEDC. The purpose of this Type VI test is the adaptation of type approval test to realistic driving conditions. Carbon monoxide and hydrocarbon emissions are limited by the Regulation.

During this In-Service Conformity test programme, two vehicles per vehicle type with positive ignition engine were tested with the type VI test at low ambient temperatures.

Table 12 show the average test results from the type VI test compared to the average test results from the Type I test of the positive ignition vehicles.

Vehicles with positive ignition engine		**Exhaust Emissions**			
Test	**Driving Cycle**	**CO [mg/km]**	**HC [mg/km]**	**NOx [mg/km]**	**CO_2 [mg/km]**
Type I test Eu5	UDC	809	102	25,3	209
	EUDC	70	3,2	9,0	125
	NEDC	341	39	15	156
Type I test Eu6	UDC	321	73	19	188
	EUDC	64	1,1	1,2	110
	NEDC	158	28	7,8	138
Limit	**NEDC**	**1000**	**100**	**60**	**-**
Type VI test Eu5	UDC	5390	820	26	257
Type VI test Eu6	UDC	8713	953	84	236
Limit	**UDC**	**15000**	**1800**	**-**	**-**

Table 12. *Exhaust emissions during Type VI and Type I of vehicles with positive ignition engine and EURO 5 emissions standard tested at -7°C*

Table 12 shows the average exhaust emissions measured during Type VI test. During the exhaust emission test at low ambient temperatures, all tested vehicles complied with the limits according to EU Regulation 715/2007/EC.

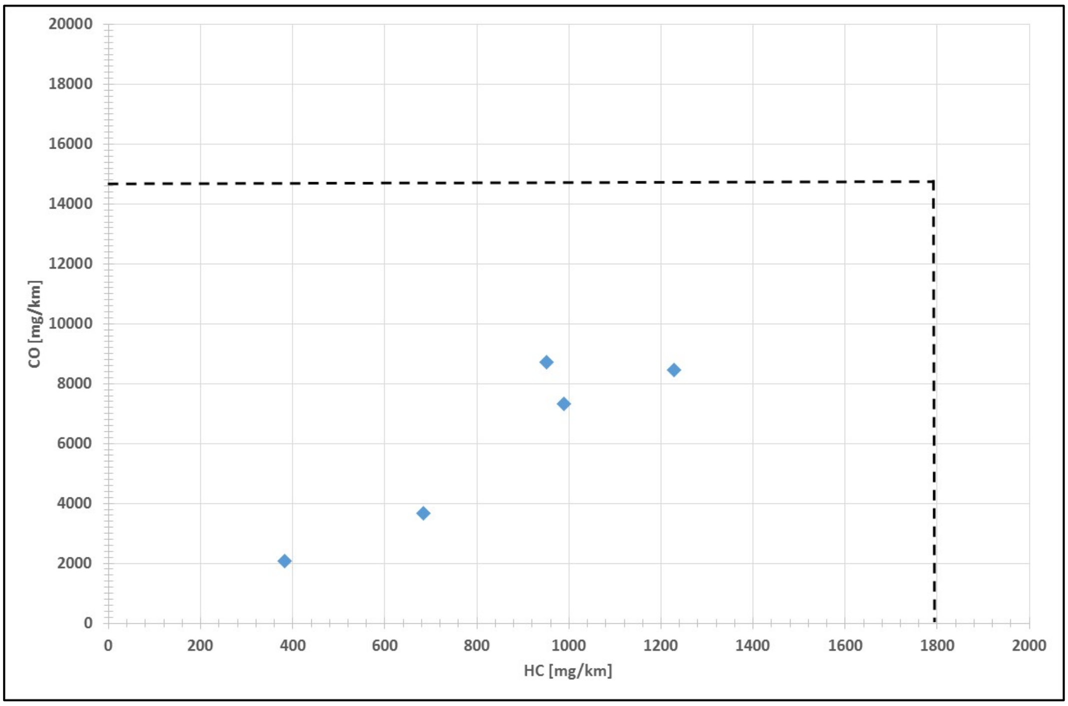

Figure 24. *Average exhaust emissions at low ambient temperatures*

Figure 25 illustrates the HC emissions during Type I test and Type VI test.

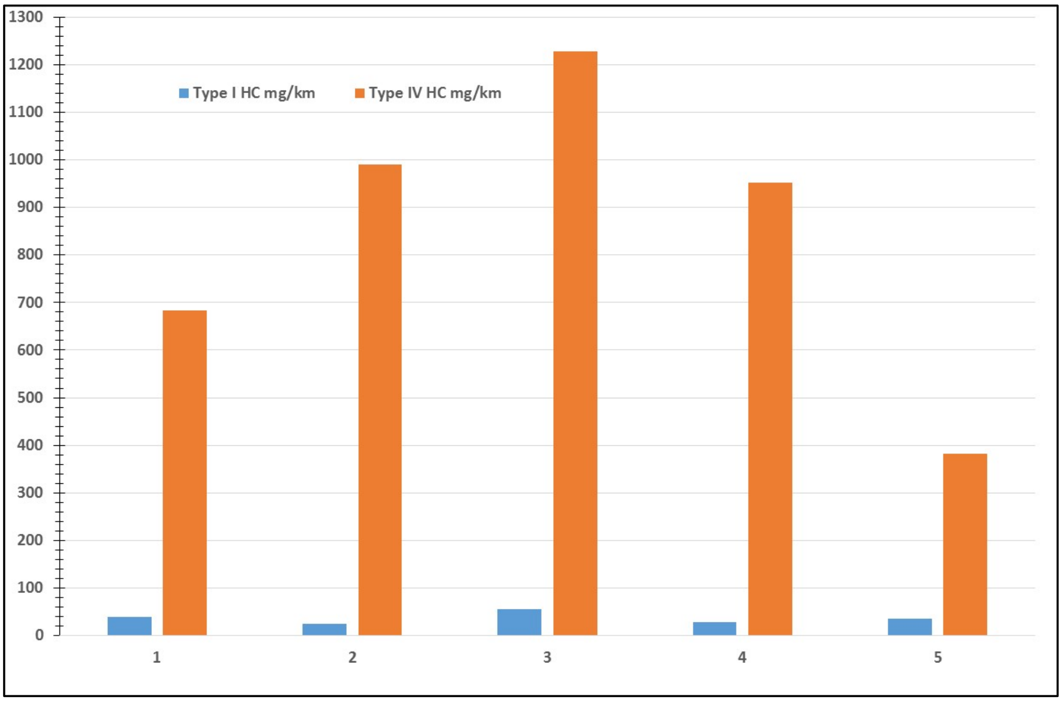

Figure 25. *HC emissions during Type I test and Type VI test*

Hydrocarbon emissions during UDC at low ambient temperature (-7°C) exceeded the exhaust emissions at 'normal' ambient temperature (20°C up to 30°C according to the regulation) by a factor of 10.

5.7. OBD System

With Directive 98/69/EC an on-board diagnosis (OBD) system for passenger cars and light-duty vehicles was introduced. The provisions for the OBD system is developed further in EU Regulation 715/2007/EC. The aim of introducing the OBD system was to achieve a significant upgrade in emission performance over the useful lifetime of vehicles in service. The OBD is an electronic system designed to detect failures of anti-pollution devices immediately, monitor critical functions of the engine and emission control systems, store additional information about deviations and assist during maintenance with fault diagnosis and fault rectification. OBD is required for vehicles with positive ignition engine registered since the 1. January 2001 and for vehicles with compression ignition engine registered since the 1. January 2004.

During this project the OBD-data were registered. In addition, some emission relevant defects were simulated to check the function of the OBD system at one of the vehicles per vehicle type. Different failures like electrical disconnection of intake air pressure sensor, disconnection of throttle position sensor, misfire, electrical disconnection of injector, disconnection of oxygen sensor (before and after catalyst) were implemented depending on the power train of the vehicles tested.

All simulated failures were detected by the OBD system.

5.8. WLTP versus NEDC

In **Figure 26** to **Figure 33** the average gaseous exhaust emissions of all vehicles tested during WLTP are illustrated.

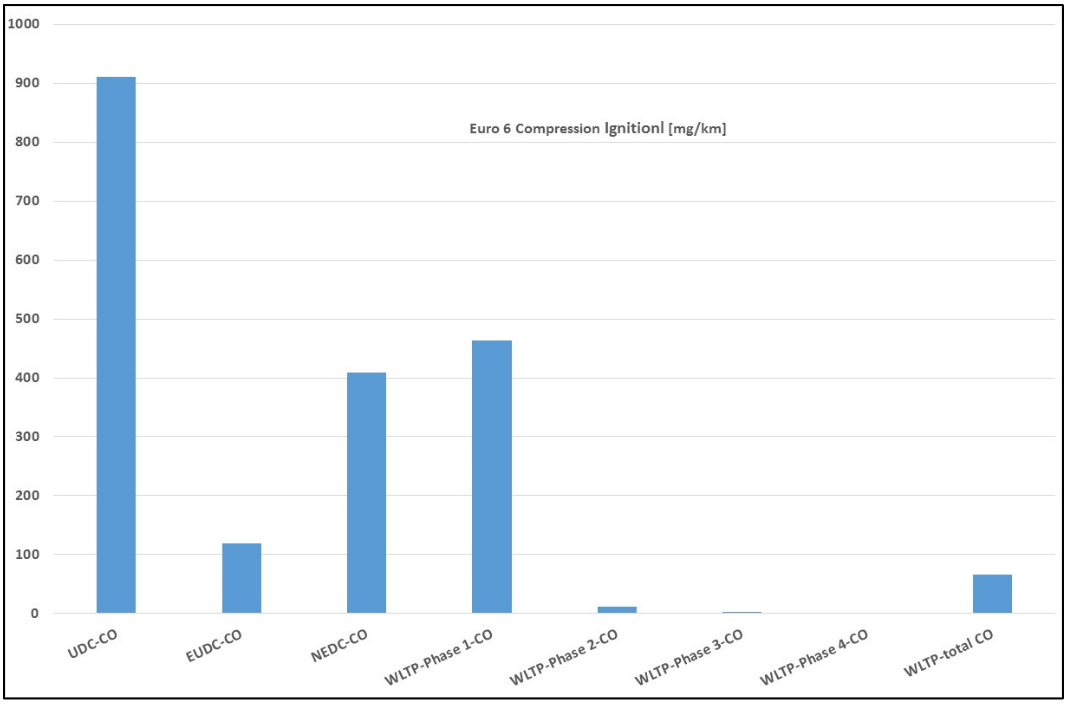

Figure 26. *CO emissions under different driving conditions EURO 6 vehicle*

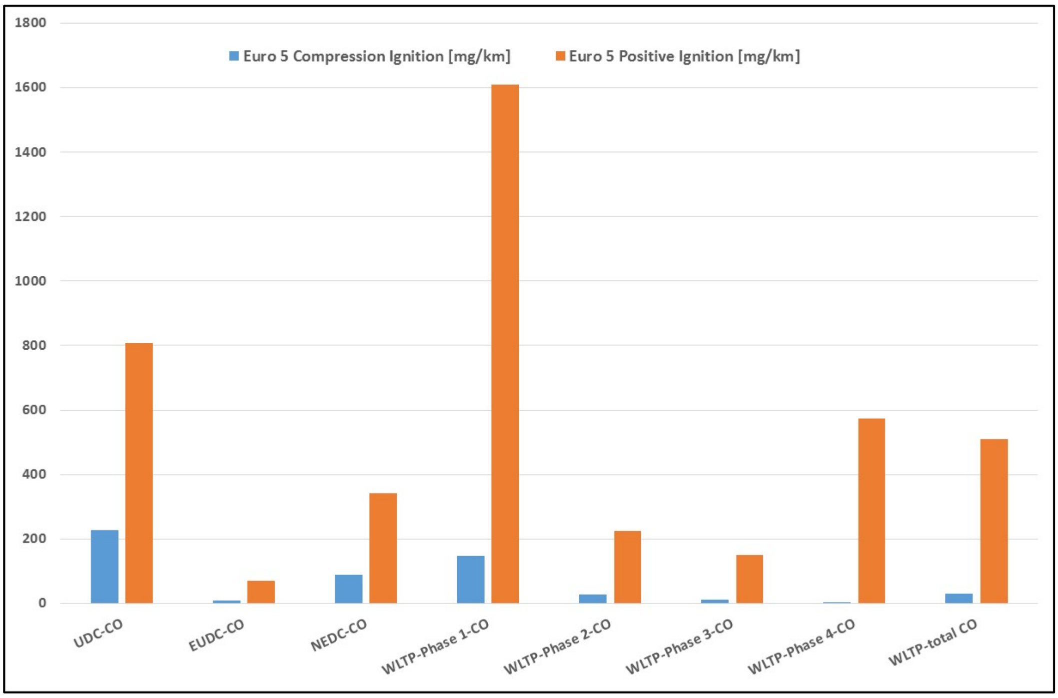

Figure 27. *Average CO emissions under different driving conditions EURO 5 vehicles*

The figures demonstrate that the major fraction of CO and HC within the New European Driving Cycle is emitted during the Urban Driving Cycle including cold start. High load and high speed during the WLTP cause increasing CO emissions on positive ignition engine vehicles. The high average CO emissions during WLTP phase 4 of positive ignition vehicles were caused by a few vehicles with small engines that showed extremely high emissions.

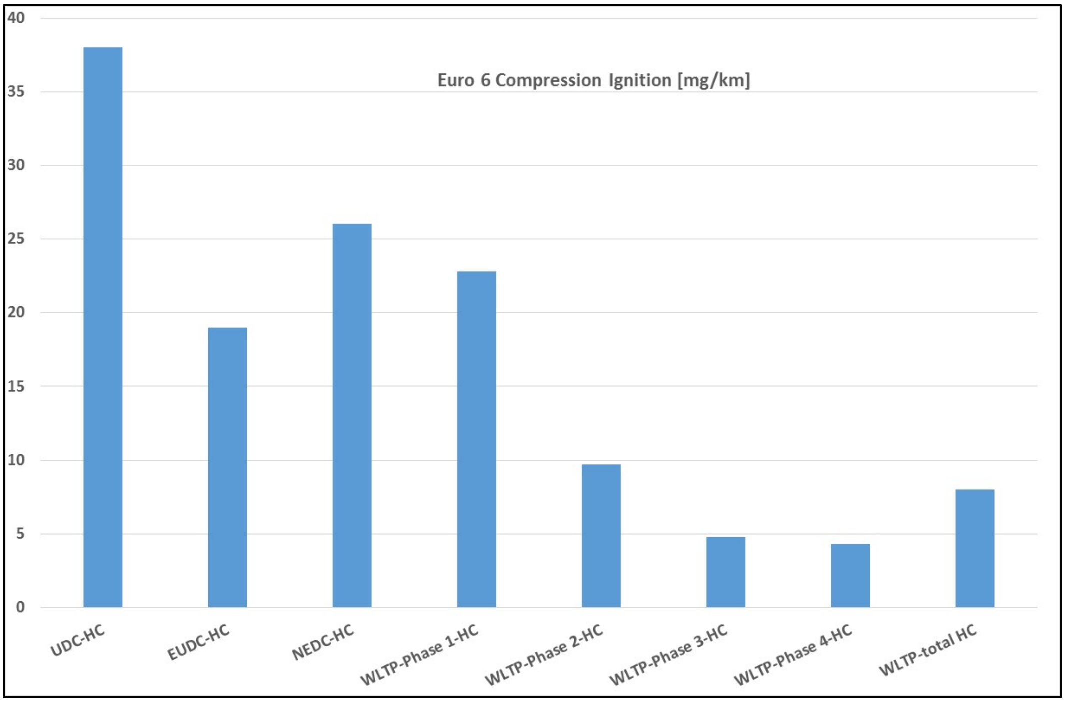

Figure 28. *HC emissions under different driving conditions EURO 6 vehicle*

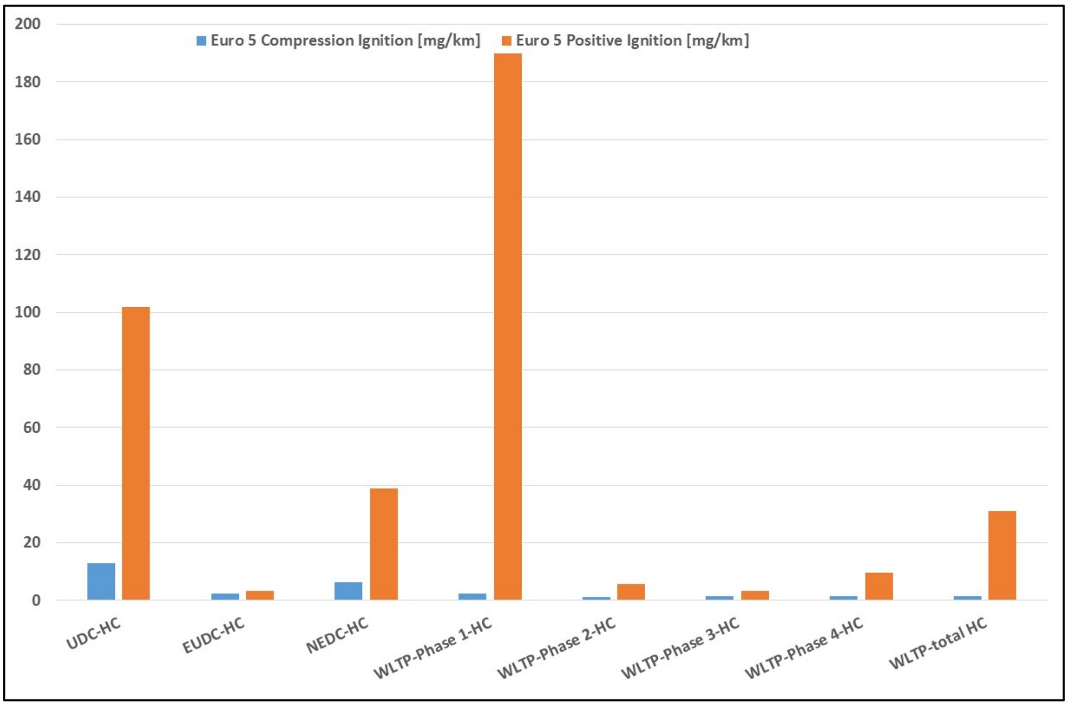

Figure 29. *Average HC emissions under different driving conditions EURO 5 vehicles*

Both CO and HC emissions are products of incomplete combustion. Therefore CO and HC are emitted at the same driving conditions. Especially at cold start conditions before the catalyst has reached its light-off-temperature and at high load with a rich air fuel ratio CO and HC are emitted because they cannot be converted. Due to a surplus of oxygen in the air fuel mixture, CO and HC emissions of vehicles with compression ignition engine are lower than of vehicles with positive ignition during all different test cycles.

Figure 30 and **Figure 31**demonstrate the different behaviour of compression - and positive-ignition regarding NO_x emissions.

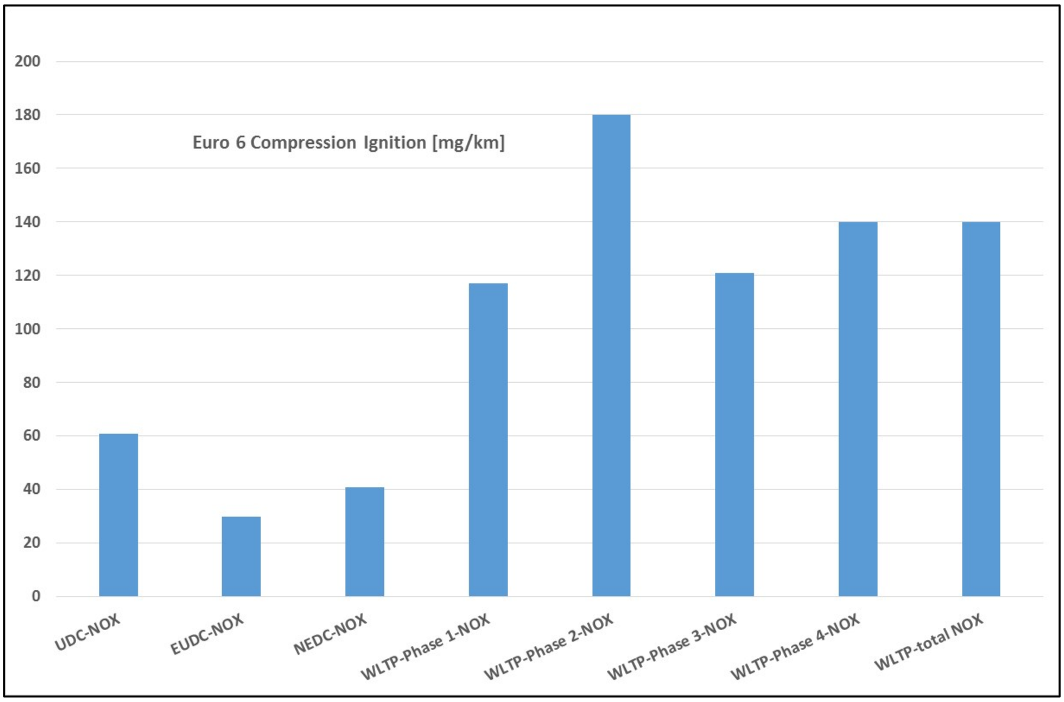

Figure 30. *Average NO_x emissions under different driving conditions EURO 6 vehicle*

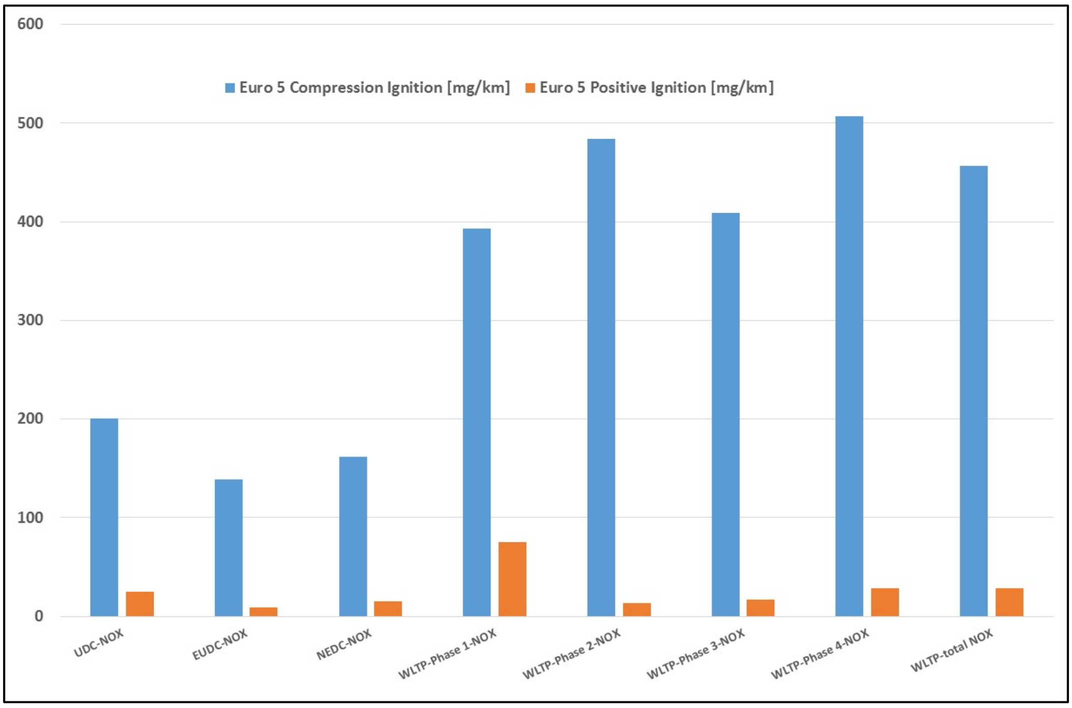

Figure 31. *Average NO_x emissions under different driving conditions EURO 5 vehicles*

The major environmental exposure caused by compression ignition vehicles is NO_x and particulate emissions. **Figure 30** and **Figure 31** illustrate that NO_x is emitted by compression ignition vehicles especially during the WLTP phase 4 cycle. This is due to the high temperature inside the combustion chamber at high engine load combined with a surplus of oxygen within the cylinder.

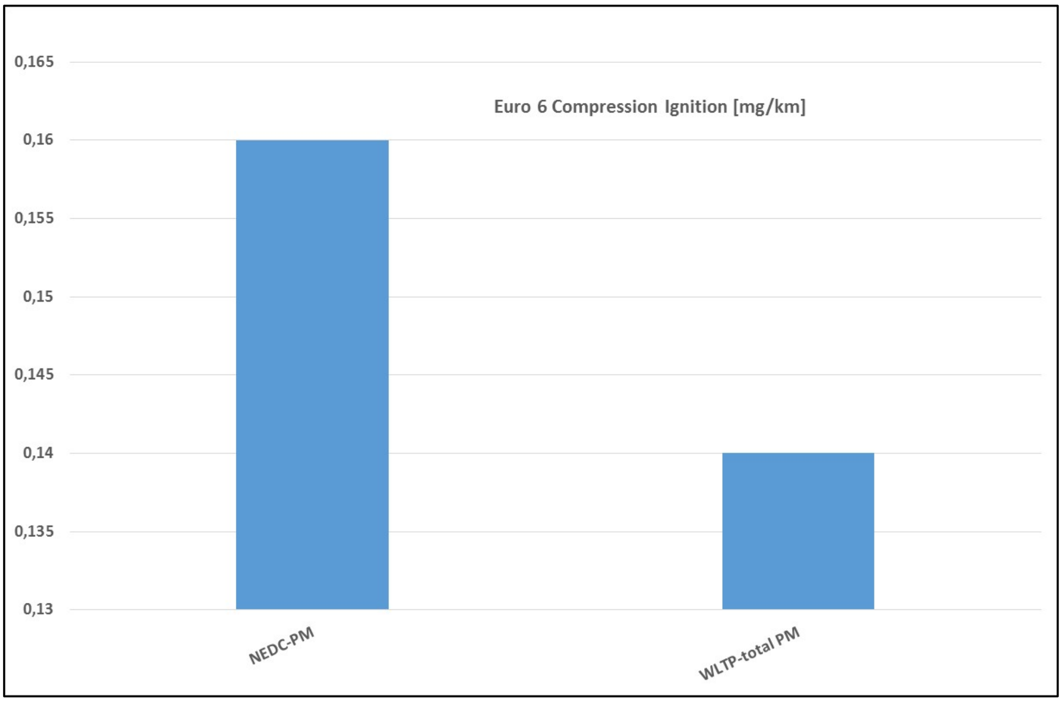

Figure 32. *Particle mass in NEDC vs WLTP, EURO 6 vehicle*

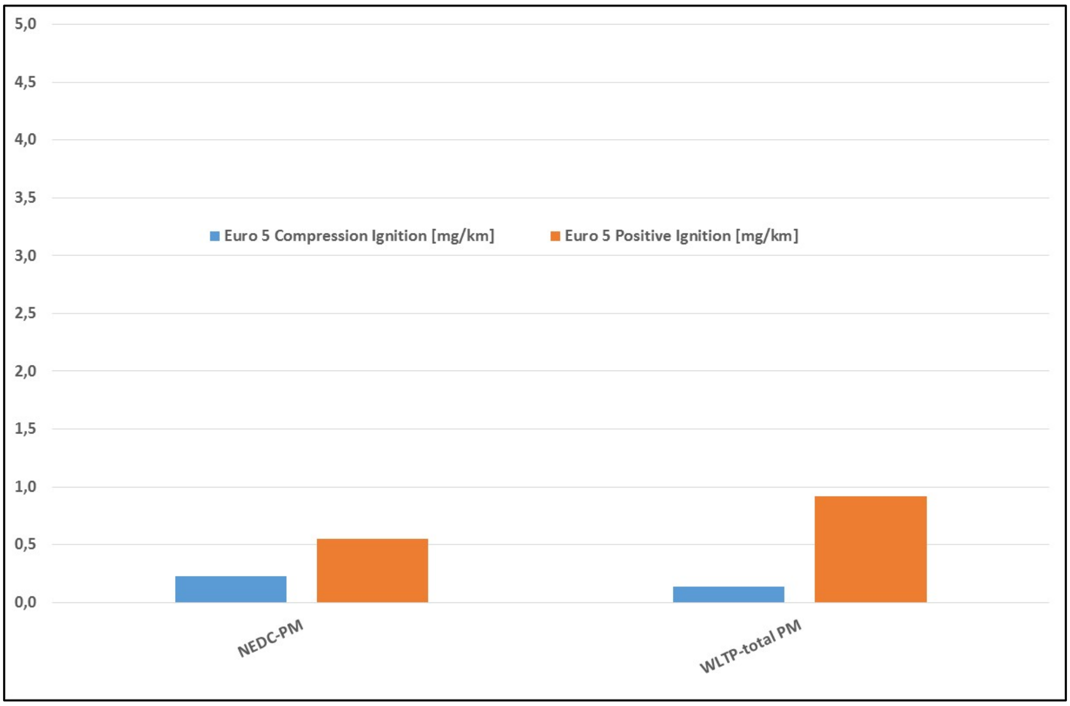

Figure 33. *Average particle mass NEDC vs WLTP, EURO 5 vehicles*

During this programme particle emissions were measured both on compression ignition and on positive ignition vehicles. In **Figure 32** and **Figure 33** demonstrated that particle mass on positive ignition vehicles is higher compared with compression ignition vehicles equiped with particle filters. It has to be considered that due to the measurement technique especially on positive ignition vehicles beside particles, condensed volatile HC might have been collected on the filter pads which could have affected the test results.

Figure 34 and Figure 35 illustrate the fuel consumption measured at different driving cycles. The average fuel consumption is given for all positive ignition and compression ignition vehicles tested during WLTP.

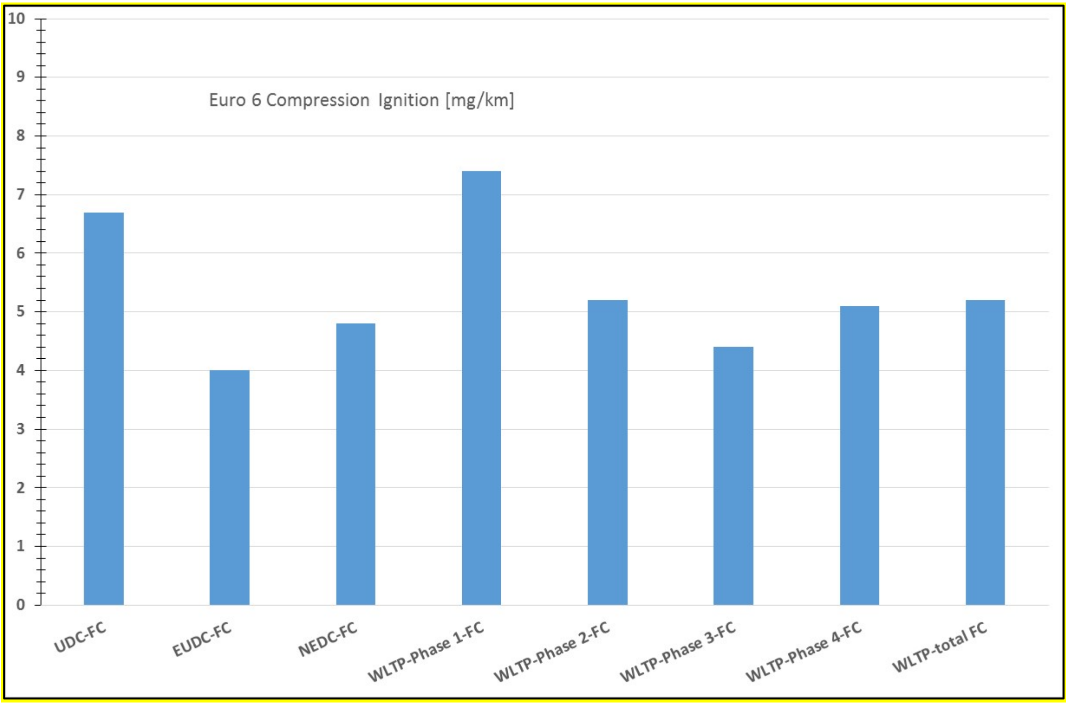

Figure 34. *Fuel consumption under different driving conditions of EURO 6 compression ignition vehicle*

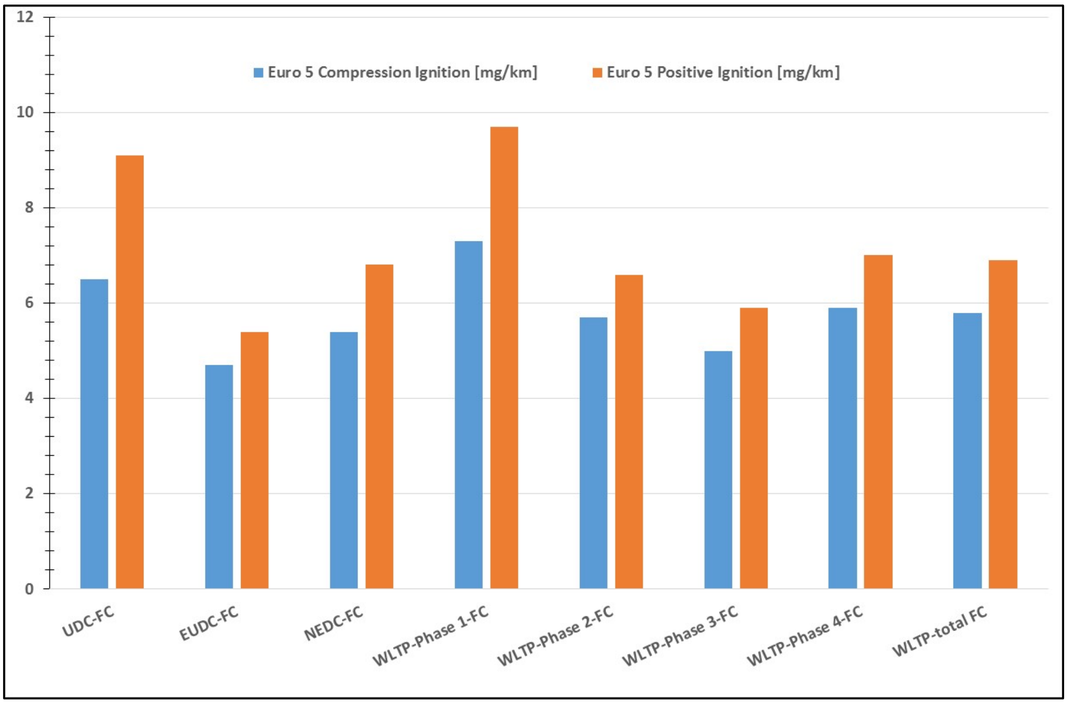

Figure 35. *Average fuel consumption under different driving conditions of EURO 5 vehicles*

5.9. Particulate Measurement

Particulate emissions from vehicles with compression ignition engine are suspected of causing diseases of the respiratory tract and cancer. Therefore, the EU Commission proposed an update of European exhaust emission legislation. The Euro 5 particulate limit for type approval of passenger cars and light duty vehicles shall be 5 mg/km. This means an 80 percent reduction of the Euro 4 limit, which has been applicable for the type approval procedure since 1. January 2005.

According to current exhaust emission legislation, the particles emitted during the Type I test are collected on filters and the particulate mass (PM) is determined by weighing these filters. For detecting low emissions expected from future compression ignition vehicles, an adaptation of the measurement technique is necessary. In 2001 the United Nations Economic Commission for Europe (UNECE) installed a working group to establish a new method of measuring particulate emissions. The conclusion of the PMP members was to modify the existing particle mass detection and to add a particle number determination.

Accuracy of particulate mass measurement shall be improved by several provisions like a high-performance inlet filter for the dilution air of the CVS system, upgraded sampling system including cyclone separator, constant sampling temperature, optimisation of the procedures for avoiding electrostatic charging and 99.9% efficiency filter pads.

In order to minimize the influence of the background emissions from the dilution air the dilution tunnel of the exhaust gas laboratory in Essen was already equipped with an HEPA filter. This High Efficiency Particulate Air Filter is intended to achieve a particle separation rate of 99.97 percent.

Directive 98/69/EC specifies the use of filters for collecting particles whose surface consist of material which is hydrophobic and inert in relation to the exhaust gas constituents. The filters must be made of fluorocarbon-coated glass fibres or equivalent material. In most exhaust gas laboratories, T60A20 filters from the company Pallflex are used to determine the particulate mass. According to the manufacturer these heat-resistant filters of fluorocarbon-coated borosilicate glass fibres exhibit a typical filter effectiveness of 96.4%. With the exhaust gas measurement during the driving cycle two filters arranged in series (collecting filter and back-up filter) are used in order to capture the largest possible quantity of particles. Pallflex provides filters of borosilicate micro-fibres which are reinforced with a glass fibre fabric and are bonded with PTFE. These TX40HI20 filters should, according to the manufacturer, achieve a typical aerosol separation rate of 99.9 percent. In view of the high filtering effect, a back-up filter can be abandoned if such filters are used.

To improve the accuracy of particle mass determination the ambient conditions for filter conditioning is regulated more stringent than in the current directive. To observe a temperature of 22°C ± 3 and a humidity of 45 percent ± 8 a new weighing chamber was installed. The dewpoint in the chamber is maintained at 9.5 °C ± 3 °C. In addition a balance with higher accuracy according to PMP suggestion was used.

In **Table 13** essential elements of the particle measurement equipment according directive 98/69/EC are compared to the new procedure according to EU Regulation 715/2007/EC

PM according to 98/69/EC	PM according to 715/2007/EC
- (HEPA filter also used during this programme)	HEPA Filter with 99.97% efficiency for dilution air
Probe with ‚China Hat‘	Probe with ‚China Hat‘ or Probe without ‚China Hat‘ combined with a cyclone
TA filters with 96.4% efficiency: one filter + backup filter per phase	TX filters with 99.9% efficiency: single filter without backup filter for both phases
Balance with 5 µg accuracy and 1 µg resolution (new balance used also during this programme)	Balance with 2 µg accuracy and 1 µg resolution
Filter conditioning at constant temperature and humidity (new weighing chamber also used during this programme)	Weighing chamber conditioning at temperature: 22°C ± 3 humidity: 45% ± 8 dewpoint: 9.5 °C ± 3 °C

***Table 13**. Particle mass determination according to directive to the current status of PMP discussion*

For particle number detection EU Regulation 715/2007/EC specifies the Condensation Particle Counter (CPC). The CPC determines the number concentration of particles contained in the exhaust emissions. The particles are enlarged by condensation and counted by the method of light scattering. For particle number (PN) detection, a complex sampling system is used. The particles are preclassified by a cyclone. The pre-classifier 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm. For counting particles, the sample has to be diluted within two steps. To eliminate condensed volatile hydrocarbons the probe is heated to a temperature between 150°C up to 300°C and cooled down again for measuring. **Figure 36** illustrates the sampling system for particle number determination.

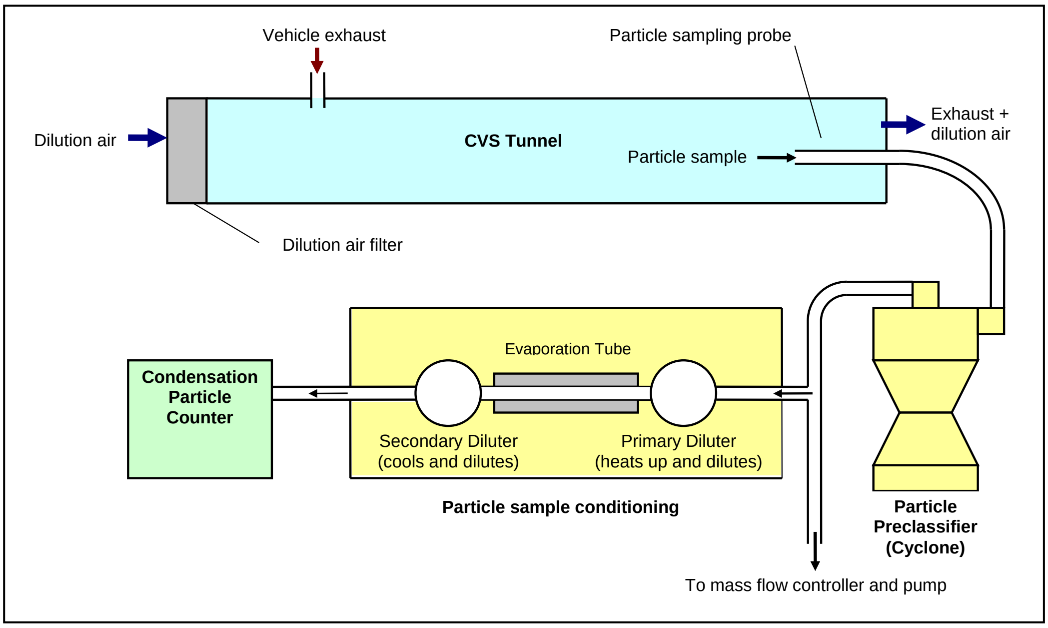

***Figure 36**. Sampling system for particle number detection*

The update of European exhaust emission legislation proposes particle limits both for vehicles with compression ignition engine and vehicles with positive ignition engine and direct injection. The limits for particle emissions are given in **Table 14.**

Category	Reference Mass (RM)	Limits Euro 5 and Euro 6					
		Compression Ignition			positive ignition Direct Injection		
	[kg]	PM [mg/km]	PM PMP [mg/km]	P-Number [#/km]	PM [mg/km]	PM PMP [mg/km]	P-Number [#/km]
M1	All	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
N1	RM ≤1305	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
	1305<RM≤1760	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
	1760<RM	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*
N2	All	(5.0)*	4.5	6.0E+11	(5.0)*	4.5	6.0E+12 / 6.0E+11*

*) Particle Number Limit for Euro 5 measured according 98/69/EC (Two-filter-method)
**) Stepwise implementation 2013: 6,0E+12; 2014 6,0E+11

***Table 14**. Euro 5 and Euro 6 limits for particle emissions*

Although determination of particle mass for vehicles with positive ignition engine according to EU Regulation 715/2007/EC is not relevant, it was done on positive ignition and compression ignition vehicles. The results are shown in **Table 15**.

		NEDC	WLTC phase 1	WLTC phase 2	WLTC phase 3	WLTC 4hase 4	WLTC total
Compression ignition Euro 6	PM [mg/km]	0,23	n.a	n.a	n.a	n.a	0,15
	PN [#/km]	4,85E11	3,37E11	1,87E10	4,47E9	4,30E9	1,52E10
Compression ignition Euro 5	PM [mg/km]	0,16	n.a	n.a	n.a	n.a	0,15
	PN [#/km]	3,89E10	1,36E11	3,65E8	2,63E8	1,27E8	1,83E10
Positive ignition Euro 5	PM [mg/km]	0,55	n.a	n.a	n.a	n.a	0,92
	PN [#/km]	7,36E11	4,00E12	7,34E11	5,77E11	9,14E11	1,18E12
Positive ignition Euro 6	PM [mg/km]	0,29	n.a	n.a	n.a	n.a	0,33
	PN [#/km]	4,81E11	2,64E12	7,23E11	4,13E11	2,87E11	7,27E11

Table 15. *Average particle mass and number determined according to EU Regulation 715/2007/EC*

Comparing the total results given in **Table 15** for WLTC total illustrate two facts:

1. Compression ignition vehicles equipped with a particulate filter do also perform well during WLTP and stay below the given limit of $6{,}0 \times 10^{11}$.
2. Positive ignition powered vehicles– direct injection (DI) as well as some multipoint injection (MPI) engines show higher emissions.

Up to now, the limit of $6{,}0 \times 10^{11}$ is not valid for positive ignition vehicles equipped with MPI engines. Figure 5.33 shows an example comparing the second by second emissions of a DI and a MPI car.

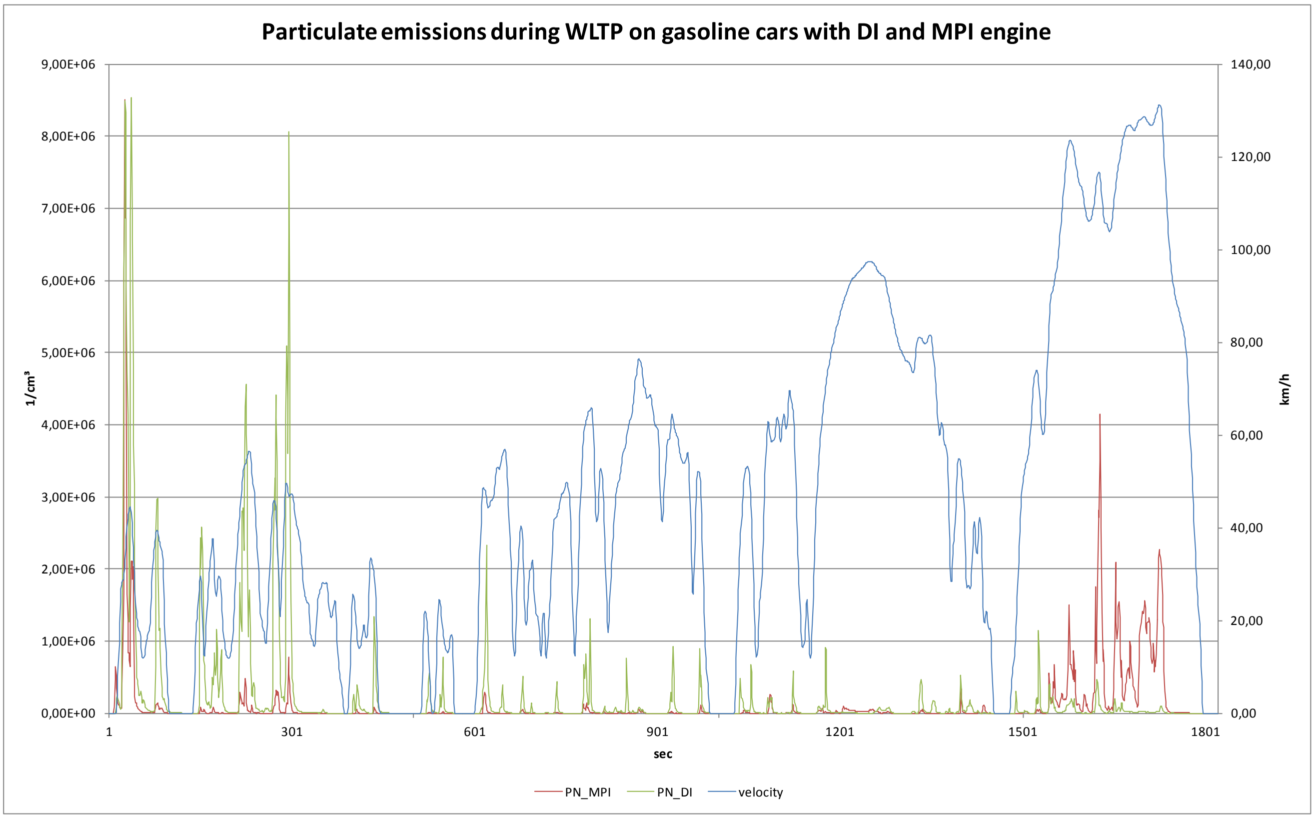

Figure 37. *Particle emissions during WLTP of a vehicle with MPI and a vehicle with DI positive ignition engine, PN MPI: 1,66E+12 [#/km]; PN DI: 2,44E+12 [#/km]*

Comparing the second by second data showed in **Figure 37** the different behaviour of DI and MPI engines become clear. The overall level of DI engines is constantly higher, MPI engines emitting Particulate emissions during cold start and high load phases (as WLTP Phase extra high). This behaviour should be taken into account when implementing a particulate number limit for WLTP.

6. References

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